STUDIES IN THE RECLAMATION OF LUBE OILS

THESIS

SUBMITTED FOR THE AWARD OF THE DEGREE OF

Doctor of Philosophy

IN

CHEMICAL ENGINEERING

BY

VINEET KATIYAR

DEPARTMENT OF CHEMICAL ENGINEERING
ZAKIR HUSAIN COLLEGE OF ENGINEERING & TECHNOLOGY
ALIGARH MUSLIM UNIVERSITY
ALIGARH-202002 (INDIA)

2011

DEPARTMENT OF CHEMICAL ENGINEERING
ALIGARH MUSLIM UNIVERSITY, ALIGARH

CERTIFICATE

This is to certify that the thesis entitled, ***"STUDIES IN THE RECLAMATION OF LUBE OILS"*** has been submitted by ***MR. VINEET KATIYAR,*** in partial fulfilment of the requirements for the award of the degree of ***'Doctor of Philosophy'*** in Chemical Engineering in the Department of Chemical Engineering, Aligarh Muslim University, Aligarh. This is a record of bonafide research work carried out under my guidance and supervision. It is further certified that the work presented in this thesis has not been submitted for the award of any other Degree or Diploma.

Date: 25.4.2011

Place: Aligarh

[PROF. SATTAR HUSAIN]
Department of Chemical Engineering
Aligarh Muslim University, Aligarh

ACKNOWLEDGEMENT

I am particularly indebted to my respected guide **Dr. Sattar Husain**, Professor, Department of Chemical Engineering, Zakir Husain College of Engineering and Technology, Aligarh Muslim University, Aligarh. The present research work is the result of his inspiration, guidance and more than that the innovative ideas. With profound sense of respect, I record my gratitude to him. He has not only polished me with his invaluable preserving guidance but also instilled confidence in me to complete this research work.

I am grateful to **Dr. Mohammad Idrees**, Chairman, Department of Chemical Engineering, for providing me the necessary facilities of the department to carry out the research work.

I am also grateful to **Dr. Syed Akhlaq Ahmad, Dr. Mohammad Junaid Khalil, Mr. Naseem Ahmad Khan, Mr. M. Abdul Hakim, Mr. Sadaf Zaidi, Ms. Aishatul Bushra, Dr. Sheeba Jilani and Mr. Raunaq Hasib,** Department of Chemical Engineering, Zakir Husain College of Engineering and Technology, A.M.U, Aligarh for their constant invigoration at each stage which enthused my work spirits.

It will be unfair on my part if I do not convey my thanks to **Dr. B.D. Agarwal,** Mineral oil Corporation, Kanpur for his timely help. I would like to acknowledge that the greatest role has been of my parents, family members, who have helped me to cultivate the systems of values and instincts that shall always enlighten my path all these living years.

Nothing would have possible without the help of my friends Mr. Pallav Singh, Mr. Rishi Pal Singh, Mr. Absihak Kumar and Mr. Nirmal Kumar.

Date: 25.04.2011

Place: Aligarh

[VINEET KATIYAR]

Research Scholar
Department of Chemical Engineering,
Aligarh Muslim University, Aligarh

STUDIES IN THE RECLAMATION OF LUBE OILS

ABSTRACT

The subject matter of the present thesis has been embodied in five chapters. The experimental work carried out on the reclamation of four used lubricating oils namely engine, gear, compressor and hydraulic oils have been described in **Chapter - 3**. The results obtained after the characterization of used and reclaimed lubricating oils have been discussed in **Chapter - 4**. The tables and figures related to each chapter have also been depicted at the suitable places of each chapter.

The first chapter on **Introduction** introduces regeneration of used lubricating oils, scope of recycling, sources of used oils, contaminants of used oils, example of used oils, recycling methods, additives for lubricating oils and environmental effects of used oils. This chapter finally highlights the aims and objectives of the present work which have been executed on reclamation of engine, gear, compressor and hydraulic oils followed by blending of suitable additives to the respective base stocks prepared.

The second chapter, namely **Literature Review,** provides up to date information related to developments in the field of reclamation of used lubricating oils. The available literature has been described under regeneration of used lubricating oils. Regeneration of used lubricating oils has been subdivided into centrifugal separation, magnetic separation, vacuum dehydration / distillation, acid refining and solvent refining.

The third chapter is **Materials and Methods**, divided into three main headings, namely Experimental Methods, Reclamation of used lubricating oils, Equipments used

in Reclamation of used lubricating oils. The raw materials required for experiments have described first. The first heading is for the Experimental methods involved during the physico-chemical characterization of the used lubricating oils, i.e. flash point, ash content, viscosity, viscosity index, pour point, colour, total acidity, inorganic acidity, saponification value and corrosion copper strip test. The second heading is for the Reclamation of used lubricating oils and third heading is for equipments used in reclamation of used lubricating oils.

The fourth chapter is **Results and Discussion** divided into five main headings, namely Characteristics of used lubricating oils, Dehydration of used lubricating oils, Solvent treatment of dehydrated oils, Clay treatment of solvent treated oils and additive blending on the characteristics of refined base stocks. Each main heading is subdivided into four parts and work on each of the four oils i.e., engine, gear, compressor and hydraulic oils related to the main heading has been described in this chapter.

After the characterization of used engine, gear, compressor and hydraulic oils, different samples of refined base stocks were prepared. The conditions of refining process were set up as described in third chapter, depending on the various characteristics of the used lubricating oils. Different samples of base stocks obtained from refining of various used lubricating oils were characterized for different properties, i.e. colour, viscosity, flash point, pour point, ash content, inorganic acidity, total acidity, saponification value and copper strip corrosion. The properties of base stocks were compared with that of used lubricating oils from which these were prepared.

The fifth chapter is that of **Conclusion and Recommendation**, which lists the outcome of the entire experimental work carried out during the course of the present research work. Analyzing the overall properties of the finished lubricating oils, prepared in the present work , it can be said that these finished oils are suitable for use in various specific fields of lubricants such as in engines, in gear boxes, in compressors and in hydraulic systems. Lastly, the **Bibliography, Appendix and List of Papers Published** have been given.

CONTENTS

LIST OF FIGURES

LIST OF TABLES

NOMENCLATURE

L	Kinematic viscosity at 40°C of an oil of 0 Viscosity index, cst
U	Kinematic viscosity at 40°C of the oil whose Viscosity index is to calculated, cst
H	Kinematic viscosity at 40°C of an oil of 100 Viscosity Index, cst
A_T	Total acidity in mg potassium hydroxide / g sample
A	Instrument calibration constant
B	Instrument type constant
t	Efflux time, s
w	Weight in g of ash
W	Weight in g of sample
V	Volume of potassium hydroxide solution in ml
N	Normality of the potassium hydroxide solution
V_1	Volume in ml of acid used in titrating blank
V_2	Volume in ml of acid in titrating the sample
W_1	Wet sludge weight
W_2	Dry sludge weight

CHAPTER - 1

INTRODUCTION

Lubricating oil is an important resource and a petroleum base product. It is used in various production machineries, power plants, automobiles etc for reducing fraction, carrying away heat, protecting against rust and wear and sealing out contaminant. There are several ways with which a lubricant can be contaminated. Particulate matters, moisture, acidic combustion products, etc. enter into lubricants. A variety of chemical additives can be used to prevent these contaminants from producing harmful effects to the components. Additives which provide dispersancy, corrosion protection, detergency and rust prevention are required.

All lubricants including automotive oils and industrial lubes, while in use, undergo changes in their properties which can seriously affect correct operation and equipment life as well. The undesirable components which accumulate with the oils during their use and which are generally responsible for deterioration are usually of two kinds of which one is extraneous impurities and other is degradation products of oil.

Used lubricating oil indicates oil after a certain running period, and is the usual name for the crankcase oil. Used lubricating oil may be more or less contaminated or deteriorated; the appearance of used oil may be clean or dirty but the name remains the same as long as the used lubricating oil is still to be considered a liquid. Used lubricants represent a problem for environment. Used

lubricants are created when all mechanical possibilities in a machine or at the user's premises no longer suffice to maintain the performance of the lubricant and especially chemical additives have been used-up and aging by products are present in the oil. Basically used-lubricating oil means any oil refined from crude oil or any synthetic oil, that has been used and as a result of such use is contaminated by physical or chemical impurities. Used oil may be considered a hazardous liquid depending on the amount of impurities that it has accumulated during use.

Petroleum oil is largely a mixture of hydrocarbon such as paraffin's, naphthenes, aromatics, and olefins. The oil containing olefins and aromatics are extremely prone to oxidation. If oil were to oxidize completely, theoretically it would be converted to water and carbon dioxide. During the service life of lubricating oil, however, only a small amount of these products are formed and the undesirable effect of oxidation is not loss of oil but the development of objectionable intermediate products. Deterioration in lubricating oil is obviously there with use but at the same time major part of the oil remains in good condition and can be regenerated effectively for which more awareness of the recovery and reclamation processes is necessary. Recycling is a generic term for processing used lube oil to regain useful material through reclamation and re-refining. The important statistical data relating to installed capacity and refinery crude throughput, productions of petroleum products, location and capacity of refineries in India, expansion of existing refineries and new refineries in India are given in Tables 1.1 to 1.3

Table 1.1 Locations and Capacity of Refineries in India

S.NO.	Name of the Company	Location of the Refinery	Capacity (MMTPA)*
1.	Indian Oil Corporation Limited (IOCL)	Guwahati	1.00
2.	IOCL	Barauni	6.00
3.	IOCL	Koyali	13.70
4.	IOCL	Haldia	6.00
5.	IOCL	Mathura	8.00
6.	IOCL	Digboi	0.65
7.	IOCL	Panipat	6.00
8.	Hindustan Petroleum Corporation Limited (HPCL)	Mumbai	5.50
9.	HPCL	Visakhapatnam	7.50
10.	Bharat Petroleum Corporation Limited (BPCL)	Mumbai	6.90
11.	Chennai Petroleum Corporation Limited (CPCL)	Manali	9.50
12.	CPCL	Nagapattnam	1.00
13.	Kochi Refineries Ltd. (KRL)	Kochi	7.50
14.	Bongaigaon Refinery & Petrochemicals Ltd. (BRPL)	Bongaigaon	2.35
15.	Numaligarh Refinery Ltd.(NRL)	Numaligarh	3.00
16.	Mangalore Refinery & Petrochemicals Ltd. (MRPL)	Mangalore	9.69
17.	Tatipaka refinery (ONGC)	Andhra Pradesh	0.078
18.	Reliance Petroleum Ltd. (RPL).Pvt. Sector	Jamnagar	33.00
	TOTAL		127.37

- Million Metric Tonnes Per Annum

Table 1.2 Expansions of Existing Refineries

Capacity expansions planned during XIth Five Year Plan has been indicated in Table 1.2

S. NO.	Name of the Company	Location of the Refinery	Increase in Capacity (MMTPA)*
1.	Indian Oil Corporation Limited (IOCL)	Panipat, Haryana	3.0
2.	IOCL	Haldia, West Bengal	1.5
3.	Hindustan Petroleum Corporation Limited (HPCL)	Mumbai, Maharashtra	2.40
4.	Hindustan Petroleum Corporation Limited (HPCL)	Visakhapatnam, Andhra Pradesh	2.50
5.	Chennai Petroleum Corporation Limited (CPCL)	Manali, Tamil Nadu	1.60
6.	BPCL, Kochi Refineries Ltd.	Kochi, Kerala	2.0
7.	Mangalore Refinery & Petrochemicals Ltd. (MRPL)	Mangalore, Karnataka	5.31
8.	Oil & Natural Gas Corporation Limited (ONGC)	Tatipaka, Andhra Pradesh	0.066
9.	Essar Oil Limited	Vadinar, Gujarat	5.50
TOTAL		**23.876**	

Table 1.3 New Refineries in India

New grassroots refineries coming up during the XIth Five Year Plan is indicated in Table 1.3

S. No.	Name of the Company	Location of the Refinery	Capacity (MMTPA)
1.	Indian Oil Corporation Limited (IOCL)	Paradip, Orissa	15
2.	Bharat Oman Refineries Limited (BORL)	Bina, Madhya Pradesh	6
3.	Hindustan Mittal Energy Limited (HMEL)	Bathinda, Punjab	9
4.	Essar Oil Limited, (EOL)	Jamnagar, Gujarat	18
5.	Nagarjuna Oil Corporation Limited (NOCL)	Cuddalore, Tamil Nadu	6
Total		54	

1.1 REGENERATION OF USED LUBRICATING OILS

The regeneration of used lubricating oils can be classified into two groups:

(a) Reclamation

(b) Re-refining

1.1.1 Reclamation

Reclamation is a purification process which removes contaminants such as solid impurities, suspended particles and water from the used oil.

1.1.2 Re-refining

Re-refining is the process by which the used lubricating oils are regenerated to products comparable to virgin oils in performance characteristics and specification. It may involve right from the primitive method of dehydration, solvent treated oil with adsorbent i.e., fuller's earth at elevated temperature under vacuum followed by filtration to the latest method of solvent extraction, hydro finishing supplemented by contact treatment with fuller's earth if necessary to obtain light colored re-refined lubricating oil base stocks. Soluble products of deterioration are asphaltenes, unsaturated compounds, sulphur color compounds and odour forming substances.

No single method is adequate enough for making the oil fit for further use. Normally a combination of methods like dehydration, centrifugation, atmospheric distillation, fractional distillation, ultra filtration, catalytic hydro treatment, solvent treatment and filtration through solid adsorbents like aluminum silicate, aqueous sodium meta silicate are employed for regeneration of used oils for obtaining good quality base oils. The important statistical data relating to the projected production of crude oil and petroleum product availability are given in Tables 1.4 to 1.5

Table 1.4 Projected Production of Crude Oil during the Eleventh Plan (2007-2012)

Company	2007-08	2008-09	2009-10	2010-11	2011-12	TOTAL
1. ONGC	27.16	28.00	29.00	28.53	27.37	140.06
2. OIL	3.50	3.55	3.73	3.91	4.30	18.99
3. Joint Venture/ Private Companies	10.57	10.78	9.76	8.75	7.85	47.71
4. Total	41.23	42.33	42.48	41.19	39.52	206.76
Actual Production	34.12	37.35	41.56			

Production of Crude Oil (MMT)

Source: Ministry of Petroleum & Natural Gas, Govt. of India.

Table 1.5 Projected Petroleum Products Availability during the Eleventh Plan (2007-2012)

('000' Tonne)

PRODUCTS	2007-2008	2008-09	2009-10	2010-11	2011-12	Total
Heavy Ends	29000	32200	38300	38000	41000	178500
1. Lubes	800	800	800	1100	1100	4600
2. FO/LSHS	14800	15600	15600	10900	9500	66400
3. Bitumen	3700	3900	4000	4000	4400	20000
4. Coke	4100	5400	8300	11000	12800	41600
5. Others	5600	6500	9600	11000	13200	45900

Source: Ministry of Petroleum & Natural Gas, Govt. of India.

1.2 SCOPE FOR RECYCLING

A large range of used oils can be recycled and recovered, either directly in the case of high oil content wastes, or after some form of separation and concentration from high aqueous content material. Certain types of used oils lubricants in particular, can be processed allowing for direct reuse. The use of used oils after treatment can be a high energy content, clean burning fuel or a lube base stock comparable to highly refined virgin oil. Reclamation of used oils can give a product of comparable quality to the original, but may contain various contaminants depending on the nature of the process such as heavy metals by – products of thermal breakdown and substances associated with specific uses (e.g. lead, corrosion inhibitors, PCBs). The regeneration of used oils is widely practiced to obtain the highest degree of contaminant removal leading to the recovery of the oil fraction, which has the maximum viable commercial value.

1.3 SOURCES OF USED OILS

1.3.1 Automotive service centers and commercial engine fleets

This includes service stations, garages, new car dealers, other retail establishments and automotive fleet service areas where used oils are drained from crankcases of automobiles and some trucks. Used oils from automotive service centers and commercial engine fleets represent the largest relatively uniform source of feedstock with good recycling capabilities.

1.3.2 Aviation service centre

The aviation industry is an important user of petroleum based fuels and lubricants. Used oil generated at major airports is likely to include: Jet fuel drained from aircraft, draining of petroleum based engine and transmission lubricants (Primarily from ground support equipment) and synthetic lubricants, which may be re - used as long as they meet specific gravity, viscosity acid number and water specifications.

1.3.3 Industrial oils

Included in this category are all industrial oils (lubricating and non-lubricating), which have as their source lubricating oil stocks, sold to industry. These include: turbine oils, engine oils, transformer oils, refrigeration oils, heat transfer oils and hydraulic oils.

1.4 CONTAMINANTES IN USED OILS

Lubricating oil becomes unfit for further use for two main reasons: accumulation of contaminants in the oil and chemical changes in the oil. The main contaminants are listed below.

- **Combustion Products: Water** - Fuel burns to Co_2 and H_2O. For every liter of fuel burnt, a liter of water is created. This normally passes out through the exhaust when the engine is hot, but when cold it can run down and collect in the oil. This leads to sludge formation and rust.

- **Soot and Carbon:** These make the oil go black. They form as the result of in complete combustion, especially during warm - up with a rich mixture.

Lead: Tetraethyl lead, which used to be used as an anti-knock agent in petrol, passes into the oil. Typical used engine oil may have contained up to 2% lead, but today any lead comes from bearing wear and is likely to be in the 2-12 ppm range.

Fuel: Un-burnt gasoline or diesel can pass into the lubricant, again especially during start - up.

- **Abrasives: Road dust** – This passes in to the engine through the air-cleaner composed of small particles of silicates.

Wear metals: Iron, Copper and aluminum released due to normal engine wear.

Chemical Products: Oxidation products - some of the oil molecules, at elevated temperatures, will oxidize to form complex and corrosive organic acids.

1.5 ENVIRONMENTALLY EFFECTS OF USED OILS

- When used oil is dumped on the ground, sewers or sent to landfills, it is capable of seeping into ground and surface water. Just one liter of used oil can render one million liters of water undrinkable.

- Toxic gases and harmful metallic dust particles are produced by the ordinary combustion of used oil. The high concentration of metal ions, lead, zinc, chromium and copper in used oil can be toxic to ecological systems and to human health if they are emitted from the exhaust stack of uncontrolled burners and furnaces.

- Certain compounds in used oil – e.g. poly-aromatic hydrocarbons (PAH) – can be very dangerous to one's health. Some are carcinogenic and mutagenic. The PAH content of engine oil increases with operating time, because the PAH formed during combustion in petrol engines accumulates in the oil.

- The high temperatures and stress of an engine's operation transform lubricating oil. This results in oxidation, nitration, cracking of polymers and decomposition of organ-metallic compounds.

- Other contaminants also accumulate in oil during use-fuel, antifreeze/coolant, water, wear metals, metal oxides and combustion products.

1.6 WHAT IS NOT USED OIL?

The materials listed below are ***not used*** oil.

■Used animal or vegetable oils (they are considered food wastes rather than used oil, because they are not synthetic and not derived from crude oil).

■ Unused contaminated or uncontaminated oils going for reclamation.

■ Solid wastes contaminated with used oil (such as absorbents and scrap metal) that are not burned for energy recovery and that do not have free-flowing oil.

■ Solvents (such as petroleum spirits, mineral spirits, petroleum ether, acetone, fuel additives, alcohols, paint thinners, brush cleaners, and other cleaners).

- Substances that cannot readily be recycled in the same processes as used oil.

- Used antifreeze.

1.7 WHAT IS USED OIL?

Used oil includes any of the materials listed below.

- Any oil, either synthetic or refined from crude oil, that has been used for its designed and intended purposes; and as a result of use, is contaminated by physical or chemical impurities; and as a result, has become a spent material (that is, it can no longer be used for its originally intended purpose without processing).

- Used oil to be burned for energy recovery.

- Any other material that has physical and chemical properties similar to used oil, is used in normally accepted functions of oil.

- Used oil that is characteristically hazardous from use (as opposed to oil rendered characteristically hazardous by mixing).

1.7.1 Examples of Used Oil

The following lists give some examples of oils that have become spent materials through use.

(i) Spent Engine Oil and Vehicle Lubricants. Used oils include, but are not limited to, the following spent engine lubricating oils and vehicle fluids:

- Automotive crankcase oil, including car, truck, marine, and aircraft engine oils not used for engine fuel
- Diesel engine crankcase oil, including car, truck, bus, marine, heavy equipment, and railroad engine oils not used for fuel
- Natural-gas-fired engine oils
- Alternative fuel engine oils
- Transmission fluids
- Brake fluids and
- Power steering fluids

(ii) Spent Industrial Oils. Used oils also include, but are not limited to, the following spent industrial oils:

- Compressor, turbine, and bearing oils
- Hydraulic oils or fluids
- Metalworking oils or oil emulsions, including cutting, grinding, machining, rolling, stamping, quenching, and coating oils; electrical insulating oils;
- Refrigerator/air conditioning unit oils
- Rubber-making oils
- Cable oils
- Greases
- Oil-like heat transfer fluids

1.8 ADDITIVES FOR LUBRICATING OILS

Petroleum additives are those materials which when incorporated in finished petroleum products, supplement their natural characteristics and improve their performance in existing application or broaden the areas of their suitability.

Additives are not only useful to produce superior products but also to lower manufacturing cost and increase the selection of crude oils from which the lubricants can be made .Almost all properties of oils can be modified by the use of additives.

Modern additive can be classified as follows into three categories:

(1) Additive designed to protect the finished petroleum products from chemical changes or deterioration in one way or another;
(2) Additive protect the machines either from harmful substances formed in the fuel or modify the lubricant to function properly;
(3) Additives which improve certain physical properties of the product [1-6].

The common types of additives are:

1. Pour point depressants
2. Viscosity index improver
3. Antriwear and extreme pressure additives
4. Oxidation inhibitors
5. Antifoam agents
6. Dyes (fluorescence improver)
7. Detergents-dispersants
8. Miscellaneous

1.9 RECYCLING TECHNOLOGIES

There are several recycling technologies. These are:

1. Acid -Clay Process

2. PROP Process
3. Sulfuric Acid Refining
4. Propane Extraction Process
5. Mohawk Technology
6. KTI Process
7. Safety Kleen Process
8. DEA Technology
9. High-Temp Clay Reclamation

The advantages and disadvantages of these processes are summarized in Table 1.6.

Table 1.6 Recycling Technologies

S. No.	Process	Advantages	Disadvantages
1.	Acid-Clay Process	It can remove solid matter, water. It can also remove products of deterioration of oil and unsaturated compounds.	Treated oil lacks in oxidation stability. Disposal of acidic sludge and oily clays.
2.	PROP Process	It can produce high yields of base oils from used lube oils. It can remove unwanted sulphur, nitrogen, oxygen and chlorine compounds and accomplishes the desired improvement in colour.	Corrosive condensates and other wastes are generated and disposal of these wastes is a problem. The base stocks produced will not meet the rigid tests of quality.
3.	Sulfuric Acid Refining	It can reduce the amount of acidic sludge and used bleaching clay generated as well as increasing the lube oil yield.	Due to the acidic sludge problem, Acid refining has largely been replaced by other methods.
4.	Propane Extraction Process	It can improve the yields and colour of the used oil.	Corrosive condensates are generated. Disposal of wastes is a problem.

5.	Mohawk Technology	It is followed by hydrogenation of the distillate at 1000 psi over a standard catalyst. Special steps realized catalyst life of 8 to12 months which was essential for the economy of the process.	It is based on the KTI process.
6.	KTI Process (Kinetics Technology International)	It can remove sulfur, nitrogen and oxygen. The yield of finished base oils is high.	Disposal of wastes is a problem. The cost of process is high.
7.	Safety Kleen Process	It can remove higher boiling chlorinated paraffins. It can reduce polynuclear aromatic.	Recovery is low
8.	DEA- Technology	It can improve technical and environmental quality of the re-refined oil. Elimination of PAH are provided by a combination of thin film distillation followed by selective solvent Extraction.	Process cost is high
9.	High-Temp Clay Reclamation	It can remove insoluble impurities. Additives are completely removed by the process.	Both capital and operating cost are such that it is seldom economical except where oil is expensive and/or difficult to obtain especially as the oil less generally.

1.10 OBJECTIVES OF THE PROPOSED RESEARCH WORK

It is evident from the above discussion that there is an acute shortage of petroleum oils and their regeneration from spent oils can supplement the supply oils of these oils. The work done is in the area of reclamation of lubricating oils. Therefore, the present study was undertaken with following objectives:

(a) Characterization of used lubricating oils such as engine oils, gear oils, compressor oils and hydraulic oils for their different desirable properties.

(b) The recovery of base oils from spent lubricating oils and their characterization.

(c) Blending of chemical addititives in base oils for obtaining products equivalent to virgin oils and study the changes in their properties by physico-chemical methods.

CHAPTER - 2

LITERATURE REVIEW

Once the service life of lubricating oil is over for a particular use, the deterioration is obviously there but at the same time major part of the oil remains in good condition and can be regenerated. There are many physical and chemical processes which have been employed valuable to recover the used oil. By incorporating suitable additives into the regenerated lubricating oils, most of the properties of the oil can be modified to produce finished oil which may have same properties as that of the virgin oil. Moreover, the environmental legislation of countries does not allow their disposal in any type of soils, rivers, lakes, oceans or sewerage systems.

2.1 REGENERATION OF USED LUBRICATING OILS

The used lubricant oil can be regenerated by various processes like centrifugal separation, magnetic separation, vacuum dehydration/ distillation, acid refining and solvent refining. These are briefly discussed as below:

2.1.1 Centrifugal Separation

N.N.Li [7] has found that wax and oil are separated by centrifugation. Chill rates more than 100 times those used in conventional processes can be employed to achieve large capacity. Plate-type crystals give highest initial settling rate and wax compaction. Crystal needles can be changed into aggregates for improving centrifugation efficiency by using modifiers.

2.1.2 Magnetic Separation

M.A. Scapin et.al. [8] have reported that the recycling process of the used mineral oils has been gaining a very important gap in the context of environmental protection. Among mineral oils from petroleum, the lubricating oils are not entirely consumed during their use; therefore, it is necessary to apply a treatment for recuperation seeking their reuse. Moreover, the environmental legislation of countries does not allow their discard in any type of soils, rivers, lakes, oceans or sewerage systems. The conventional treatment has shown certain difficulties in the recuperation process for used oils. The ionizing radiation process is renowned in the industrial effluents treatments due to its high efficiency in the degradation of organic compounds and in the removal of metals and radicals.

2.1.3 Vacuum dehydration / distillation

Jesusa Rincon et.al. [9] have described that by the proper selection of components and compositions, a composite solvent to recover base oil from used lubricant oil has been formulated. The composite solvent has two single components: methyl ethyl ketone (MEK) and 2-propanol. The best extraction results were obtained when the single solvents selected were mixed at a 2-propanol /MEK ratio of 3 g/g. However, this solvent was still unable to completely remove metals and oxidation products. To solve this problem, very small quantities of KOH [from 1 to 7 g/ (kg of solvent)] were added to the composite solvent and its effect on both the extraction yields and the quality of the oil recovered was determined. A KOH concentration of 2 g/ (kg of solvent) were found to be the most appropriate. The vacuum distilled oil pretreated with

this solvent (2-propanol/MEK at a weight ratio of 3 g/g with 2 (g of KOH)/ (kg of solvent)) was almost similar to virgin oil and, therefore, suitable for the formulation of new lubricants.

Bob Boughton et.al. [10] have investigated that management of used oil has local, regional and global impacts. Because of the globally distributed nature of fuel markets, used oil as fuel has localized and regional impacts in many areas. In this paper, the human health and environmental tradeoffs of the management options are quantified and characterized. The goal of this study was to assess and compare the environmental impacts and benefits of each management method in a product end-of-life scenario using a lifecycle Assessment (LCA) approach.

William P.Hettinger et.al. [11] have obtained that automobiles and other machines employing internal combustion engines required various lubricants such as crankcase oil, hydraulic transmission fluid and the like for the operation of the various components of the machines. Periodically these lubricants are drained from the engine and removed because they are dirty, they have acquired an undesirable acidity and have developed a certain amount of sludge, all of which decrease the lubricating power of the material to such an extent that it is advisable to exchange it for new lubricant.

Jesusa Rincon et.al. [12] have described that dense propane has been used as a solvent for the continuous countercurrent extraction of base oil from waste lubricant oil. The aim of the work has been to identify the best processing conditions to separate base oil suitable for the formulation of new lubricants, avoiding the co-extraction of waste-oil impurities such as oxidation products

and metallic compounds. Experiments have been performed during 6 h in a 1.7 m extraction column operated counter currently at 30 kg/cm^2 and using an oil flow rate of 0.5 g/min. The effects of operation variables such us solvent / used oil ratio, column packing, and column temperature gradient have been investigated.

Seung-Soo Kim et.al. [13] obtained that kinetic tests on pyrolysis of waste automobile lubricating were carried out with a thermo gravimetric analysis (TGA) technique at heating rates of 50, 100 and 200°C min-1 in a stirred batch reactor. The main region of decomposition of waste automobile lubricating oil was between 400 and 460°C at each heating rate. The corresponding kinetic parameters including activation energy were determined by the degree of conversions. The ranges of activation energies were from 281.78 to 447.66 kJ mol at conversion in the range of 0.11– 0.96 and the reaction order was 1.35.

R.E.Linnard et.al. [14] described that the Phillips re-refining process combined chemical demetallization with hydro treating to produce high yields of base oils from waste lubes. Efficient re-refining of automotive drain oils is as achievable and as essential as recycling aluminum and new print, regenerating catalysts or treatment of waste paper for re-use. Used oils can now the must be viewed as assets than potential liabilities. PROP is an advanced oil re-refining technology developed by Phillips Petroleum Company that restores used lubricating oils to their original quality. PROP does this without the environmentally questionable use of acids and or solvents and without vacuum distillation. Pretreatment of waste oil feed stock is not required. The process combines unique and proprietary chemical demetallization with hydro treating

to produce high yields of base oil of quality at least as good as the base oil blending stocks of the original oil prior to its use and from which the waste oil evolved.

E.A. Malick [15] explained the prop process could produce a great variety of re-refined oils. All re-refining facilities produce a re-refined oil base stock and a distilled slight end fuel oil fraction, some of which is used on site for heating. The by products which have marginal value include distillation bottom and demetallized filter cake. It is reported that the drain on the world petroleum reserves could be cut by an estimated 100 million barrels a year.

S.Whisman et.al.[16] described that used automotive lubricating oils re-refined by a process that effectively removed contaminants and returned the oils to a equivalent to oil produced from virgin stocks. The process in-corporate a solvent step to reduce coking or fouling precursors in the subsequent full vacuum distillation and clay contracting produce fractions from used lubricating oils that have a bland odor and good color-blending and formulation with additives produce a finished oil that has successfully passed engine sequence the processes are essentially neutral and present a minimal disposal problem.

Kalnes [17] developed an economical way of rejuvenating used oils for reuse as lube oil base stocks or as feed stock to existing petroleum up grading facilities, besides the toxic by products. One of the complex issues posed include making sure that oil that can be re-refined or recycled and is not listed as a hazardous waste by EPA. Additionally the high cost of traditional re-

refining operations has limited the amount of used oil being recycled. Instead the reaches say much used lube oil is being improperly disposed of or misused as a dust suppressant or pesticide. Public participation will be needed in the collection of spent oil. He estimates that at least 1.3 billion gallons of used oil can be collected.

C.Selby et.al. [18] suggested that essentially hydro-treatment of the used oil feed stock of re-refiners can give products equivalent to those made from refined base oils. The data from the North American database of many hundreds of marked engine oils does not support a generally altitude toward engine oil made from re-refined products rather these oils have promise in adding lubricant quality to the engine oils on the market.

P.R. Crowley [19] described that the re-refining of used lubricating oil is rendered very difficult due to the presence of lube oil additives. Not only are the lube oil additives difficult to remove, but they inter-fere with the removal of other impurities. Previous re-refining processes have had difficulties as to equipment maintenance, the quantity and quality of oil removed and the disposal of heavy viscous bottoms fractions. One present method of re-refining used lubricating oil is to propane solvent-extract the used oil to obtain a propane oil solution and a bottom fraction containing the insoluble impurities.

E.W.Wood et. al. [20] have found that materials contained in a typical used crankcase oil that are considered to contribute to the ash content of the oil include sub-micron size carbon particle inorganic materials such as atmospheric dust, metal, particles, lead and other metal compounds originating from fuel combustion. Besides lead, which is generally present at concentrations of 1.0 to

2.5 weight percent appreciable amounts of zinc, barium, calcium, phosphorus and iron are also present in the used crankcase oil.

M.M.Johnson [21] studied that a process for reducing the ash content and the content of metals present in used motor oils by contacting the used motor oil with aqueous sodium of ammonium sulfate and or ammonium bisulfate under conditions to react with the metal compounds present to form separable solids. In another embodiment of the invention, the used motor oil after reaction with an aqueous solution of ammonium sulfate and/or ammonium bisulfate can be further treated with an adsorbent and then optionally hydro- treated to produce an oil product suitable as a fuel or as a feedstock for lubricating oil compositions.

E.Eckhard [22] have investigated a process for reclaiming used hydrocarbons oils through pre-purification by means of coagulation, adsorption, filtration, distillation and after treatment, wherein said oils are pre-purified and then dehalogenated, fractionally distilled and hydrogenated. It is preferred that for the pre-purification, said coagulation and said adsorption are carried out by means of a hydroxide or hydroxide mixture preferably aluminum and/or ferric hydroxide in a proportion of 0.5-5.0% by weight, preferably 1-2% by wt of hydroxide .

M.L.Whisman et.al. [23] have mentioned that re-refining process is described by which high quality finished lubricating oils are prepared from used waste lubricating and crankcase oils. The used oils are stripped of water and low- boiling contaminants by vacuum distillation and then dissolved in a

solvent of 1-butanol, 2-propanol and MEK which precipitates a sludge containing most of the solid and liquid contaminants, unspent additives and oxidation products present in the used oil.

H.B. Shoemaker et.al. [24] discovered that the desirable compounds of a used oil or oxidized oil can be separated from undesirable components by means of liquefied propane. It has been believed that hexane completely precipitates asphaltic matter from petroleum oils. However, he found that whereas hexane only precipitated 0.4% of sludge from spent oil, propane precipitated 12% and the propane sludge contained not only asphaltic matter but acids and other oxidation products.

Pierre Grandvallet et.al [25] have reported that the invention is directed to a process to further upgrade pre-processed used lubricating oil. He described a process to prepare pre-processes used oil by removal of solids, low boiling compounds and polycyclic compounds from used oils. The pre-processed used oils as obtained by such a process can not directly use as, lubricating base oil to formulate new lubricants.

C.R. Mellen [26] studied a novel process and related apparatus for removing common contaminants from used motor oil. Propane, butane or similar solvent is mixed with the contaminated oil to form a solution. This solution is agitated and then given time to settle thus allowing gravitational separation of asphaltic pollutants. The solution is then percolated through a columned filter to remove heavy metallic contaminants and the solvent recovered by heating the solution.

C.T. Mead et.al. [27] have found that used lubricating oil is reclaimed by vacuum distillation. The bottom is vacuum pyrolzed with limestone to form a virtually insoluble coked mass containing insoluble metal carbonates and free metal. This solid coked residuum is suitable for land-filling.

L.C.Fletcher et. al. [28] have reported that used oil is refined by distillation to remove a volatile forecut followed by further distillation with recirculation provisions to obtain the desired fractions of lubricating oil products while reducing the vaporization temperature of the oil. The recycle effect tends to reduce coking and cracking while providing a greater recovery of lubricating oil products through the carrier effects of the light ends.

Alessandra Borin et.al. [29] discovered that Multivariate quality control in conjunction with fourier transform infrared spectroscopy were used to qualitatively detect the class and the condition of lubricating oils. The multivariate approach was based on principal component analysis, first to classify the lubricating oil type and then to develop two control charts.

A.Agoston et.al. [30] have found that lubricating oil in internal combustion engines is exposed to various strains depending on the operating conditions, the fuel quality, the ambient conditions and operating parameters. The rate of deterioration strongly depends on these influences. In order to avoid an engine failure, the oil must be changed before it losses its protective properties. At the same time, an unnecessary oil change should be avoided for environmental and economical reasons.

C. Laird Fletcher et.al. [31] have reported a process for the reclamation and re-refining of waste hydrocarbon lubricating oils. In particular, the invention provides an extraction process for removing impurities from waste oil that has been fractionated into light and heavy lube fractions. Large and increasing volumes of used lubricating oil, particularly crank case oils from diesel and internal combustion engines are produced each year. These waste oils are contaminated with oxidation and degradation products, water, fine particulates, metal and carbon oil additive products.

G.Carlos et.al. [32] described that detecting and rejecting the used mineral motor oils containing polychlorinated biphenyls and /or polychlorinated triphenyls before filtering ; before the decantation and /or distillation step, if necessary, submitting the used mineral motor oil to thermal shock treatment. In the recycling process, stabilizing the used mineral motor oils that normally contain heavy metals by adding to bitumen, using 0 to 15 percent of used mineral motor oil and a minimum of 85 percent bitumen for bituminous pavements and 1 to 20 percent of used mineral motor oils and minimum of 80 percent bitumen for bitumen emulsions and paints.

Erich-Klaus Martin et.al. [33] directed to a method of cleaning and reclaiming used oils, especially used engine and lube oils, by filtering, heat treatment and stripping of the light ends comprising solvents and water. Used oils, especially used lube oils, after rough filtering are mixed with an aqueous solution of water glass and an aqueous solution of polyalkyane glycol while stirring at elevated temperature, the obtained mixture is allowed to settle , the

settling are separated and water and light ends are removed from the oil phase by distillation.

Quang Dang et.al. [34] regenerated used oils comprising contacting the same with a light paraffinic hydrocarbon as solvent, separating from the resulting mixture a solution of clarified oil and a residue , separating a substantial portion of the solvent from the clarified oil in a first flash zone , separating substantial the rest of the solvent from the clarified oil in second flash zone, admixing with the residue a viscosity lowering agent, separating a substantial portion of the solvent vapors from the resulting mixture in a third flash zone and further separating substantially the rest of the solvent vapors from said residue in a fourth flash zone, condensing the solvent vapors from first, second, and fourth zones and admixing the resulting condensate with the solvent vapors from the third zone.

J.A. Aramburu [35] re-refined used petroleum oils by extraction with aliphatic solvents, wherein after eliminating the extract solvent, the process consists of the following treatments (a). flash, continuous vaporization, at atmospheric pressure or near atmospheric pressure, to separate the light fraction, in the presence of small amounts of a basic compounds or a reducing agents or a combination of both and (b) continuous distillation, in a fractionating column, of the bottom liquid obtained in stage first.

Jesusa Rincon et.al. [36] has been used propane as a solvent for the recycling of used lubricant oils. The aim of the work has been to identify the best processing conditions to separate base oil suitable for the formulation of new lubricants, avoiding the co-extraction of oxidation products and metallic

compounds. The effect of pressure (30-60 kg/cm^2) and temperature (20-140°C) on the separation efficiency and yields has been investigated. In the pressure range analyzed, almost no effect of the variable on yields and metallic compounds removal more efficiently at low pressures.

A.Krzymien et.al. [37] described that rheological properties of lubricating oil decisively affect the engine internal power loss. An increase in engine mechanical efficiency can be achieved through the reduction in engines power loss caused by friction. He found some results of an experiment carried out on a SI engine lubricated with three types of lubricating oil.

M.Alves dos Reis et.al. [38] re-refined waste motor oils by treatment with a solvent that dissolves the base oil and flocculates some of the additives and impurities. He compared the performance of ketones and alcohols that are miscible with base oils at room temperatures. The results indicate that the flocculating action of polar solvents in waste oils is, basically, an anti-solvent effect exerted on some non-polar macromolecules.

G.Pignalosa et.al. [39] proposed a flow injection system for the determination of metal - based additives in lubricating oils. The system, operating under computer control uses a motorized syringe for measuring and injecting the oil sample in a kerosene stream. Where it is dispersed by means of a packed mixing reactor and carried to an atomic absorption spectrometer which is used as detector. Zinc was used as model analyst. Two different systems were evaluated. One for low concentrations (range 0-10 ppm) and

second capable of providing higher dilution rates for high concentrations (range 0.02%-0.2% w/w). The sample frequency was about 30 samples/h.

Harry levin et.al. [40] have found that the sludge is muddy or slimy, instead of dry or solid, because it occludes oil. Since the amount of oil occluded continually decreases as the period of settling increases, it is impractical and of little significance to determine the mud or slime accurately. Therefore the proposed method for the determination of un-dissolved sludge measures only the non-oily component-that is, the characteristic constituent.

2.1.4 Acid refining

M.Alves dos Reis et.al. [41] obtained that waste lubricating may be re-refined by treatment with an organic solvent that dissolves base oil and flocculates the major part of additives and particulate matter. This operation is intended to substitute the classical reaction with sulfuric acid, which generates an acid sludge, creating difficult disposal problems. The solvent developed by the author, a solution of potassium hydroxide in 2-propanol and a hydrocarbon, segregates an organic sludge from waste oils. This sludge may be used as a component of asphalts or, better, as a component of offset inks, consequently increasing the value of waste oils. This paper describes how the fundamental extraction flocculation operation is integrated in a re-refining plant. Pilot plant results described here have shown that the proposed technology produces recycled oil with properties quite similar to virgin oils.

Mohammad Shakirullah et.al. [42] demonstrated the review of some acid processes as well as development of some new solvent processes for

reclamation of used lubricating oils. The conventional processes are found to be of low yield (50%), laborious, time consuming and environmentally hazardous, because of residual acidic sludge. Based on the findings, a new modified aluminum sulphate-sodium silicate-acid-base method employing a small quantity of acid and giving a high yield (60%) is proposed. Further, to avoid use of acid, new regeneration processes based on solvent extraction were investigated. They are termed CCl_4-alcohol method, and Toluene-alcohol method. These processes are not only cost effective in terms of complete solvent recovery, but are rapid, less time consuming, more environmentally friendly and gave a high yield (70-75%).

Heitor Breno et.al. [43] suggested that anodic stripping voltammetry with a hanging mercury drop electrode was used to determine zinc in automotive lubricating oils. An experiment design was carried out in order to optimize the experimental conditions of ultrasonic extraction (20 mg of sample for 60 min), with the aid of heating (90°C), HCl (2.0 ml), and H_2O_2 (2.0 ml). The procedure provided stripping waves with good repeatability and relatively small errors, with a determination limit of 6 mg for only 30 s of deposition time. Furthermore, the method dispenses with the use of toxic solvents, high purity reagents, or as sophisticated apparatus and is suitable for routine analyses of additives, as well as for used and unused lubricating oils (synthetic or mineral ones).

G.Mazzanti et.al. [44] described the more common acid-clay treating or other clarification system .Ordinarily, a high ash content in the used oil feed would interfere with furfural extraction, but a scheme is proposed to over-come this problem. A series of bench test explored treating techniques already used

within refineries, except for some procedural modifications dictated by the difference between virgin oils ordinarily handled by refiners and the used oils to be re-refined. The used oil is first treated to remove water and gasoline. It is then treated with propane to remove asphaltic materials and at the same time to reduce the ash content such as to permit selective furfural extraction and eventually, hydro finishing. The reduction of ash content was found to be extremely because ash content is an index of the substances which create emulsions that interfere with separation by furfural. The ash can also cause deposits on the catalyst of the hydro finishing stage. The overall result is an uneconomical process.

2.1.5 Solvent Refining

W.Dennis et.al. [45] obtained that used oils was an excellent example of a high-volume recyclable commodity that could be turned from a waste into valuable products. Debate concerning the degree of hazard posed by improper management of used oils relates to the typical contaminants one might find. Samples were taken for this study at every step within a used oil management system, including re-refining. Concentrations of chlorinated solvents, three metals (Cd, Cr and Pb) and polynuclear aromatics are compared for each step and with past studies.

Didier Gourgouillon et.al. [46] suggested that filtration and concentration commentated in terms of permeate flux enhancement and metal retention. The behavior of these fluids during filtration exhibits significant discrepancies from the one observed with previously investigated model compounds. The presence of many pollutants can explain the lower improvement in the latter case. The performance of the membrane with regard

to the retention of metals is very satisfactory: in the case of zinc and copper, the separation is higher than 99.5%. The 32 h concentration run carried out at 393 K made it possible to regenerate 96% in mass of the used oil and to confine the majority of the metals in a black gum extremely viscous.

Jesusa Rincon et.al. [47] studied the action of some solvents (2-propanol, 2-butanol, 2-pentanol, methyl ethyl ketone, and methyl n-propyl ketone) on both yield and quality of the recovered oil has been investigated. The quality has been assessed through the measurement of metallic, polymeric, and oxidation compound concentrations in the extracted oil. Experimental results have shown that extraction yields increase with increasing solvent/oil ratios up to a point at which they stabilize. When comparing alcohols and ketones it has been found that yields obtained with solvents of equal numbers of carbon atoms are similar and increase with increasing solvent molecular weight for both families.

J.P. Martins [48] re-refined used lubricating oils with organic solvents that dissolve base oil and segregate the additives and solid particles. The present paper emphasizes the composition effect on the efficiency of a ternary solvent composed by n-hexane/2-propanol/1-butanol. Using the ternary diagram of waste oil/basic organic component/polar compound containing 3 g/L KOH where the phase envelope and the curves of constant sludge removal are plotted, it is proposed the composition of 0.25 waste oil/0.35 n-hexane/0.40 polar compound (80% 2-propanol + 20% 1-butanol, with 3 g/L KOH) for the process.

Jelena Lukic et.al. [49] explained that extraction with N-methyl-2-pyrrolidone (NMP) via the three-stage mixer–settler operation was studied as

possible process for re-refining of waste mineral insulating oil. The following extraction process parameters were investigated systematically in order to determine their optimum values: amount of water as co-solvent in NMP, extraction temperature and Solvent/oil ratio. The process parameters and resulting oil chemical compositions were found to influence the electrical properties and the oxidation stability of the re-refined oil. The levels of aromatic, paraffinic and polycyclic aromatic hydrocarbons were determined using IR spectroscopy and HPLC, while other relevant chemical and electrical properties of waste and re-refined oil determined ASTM standards.

Ricardo queiroz et.al. [50] determined of trace amounts of silver in used lubricating oils by electro thermal atomic absorption spectrometry (ETAAS) were developed and evaluated in terms of their analytical performance. The first method involved direct sampling in the furnace (using either platform or filter furnace technique) after dilution with an organic solvent mixture. In the second method, silver was determined after a previous microwave digestion of the oil samples. Finally, oil samples were introduced in the furnace in the form of oil-in-water micro-emulsion. The three procedures have similar detection limits but the emulsification method allows a higher sampling throughput.

J. Bishop et.al. [51] represented a vital long range energy program to be considered by the HPI .Produce a quality level of re-refined oil and submit it to the necessary engine performance tests to verity that it can meet manufacturer's new car warranty requirements and give engine performance equal or better than first run lubricating oil blended from crude oil stock and verify solvent extraction and distillation as a suitable substitute for acid treatment that presently for acid treatment that presently generates tons of

undesirable acid sludge waste. Vaporization is an essential step in this or any other recovery scheme that uses distillation to separate a clean oil fraction from extraneous matter and oil deterioration products in waste oil.

S.R. Bethea et.al. [52] describe that the responsible disposal of used lubricating oils is a serious problem. Recent impetus on waste recovery leads to renewed interest in re-refining to convert this used oil into useful products. Yet conventional re-refining can also lead to waste by products: spent acid, spent caustic, spent clay, sulfur dioxide and other. The process includes distillation of the used oil to obtain a lube distillate which is then hydro fined.

M.J.Chaddha et.al. [53] suggested that reclamation or re-refining of used engine-lubricating oil has always been a subject of continuous interest to industrialists and entrepreneurs. With the increase in the growth of automobile and transport industries, the demand for engine lubricating oil is increasing day by day. The development of re-refining industry in India started in the real sense from the year 1975. Engine lubricating oil is stored in the crank - case of a 4-stroke engine and it lubricates the piston-cylinder assembly by flowing past, the piston rings in small quantities. The oil has to be drained or changed after every 4800 km or as per automobile manufactures.

Elena Dominguez-Rosado et.al. [54] reported that the decomposition of used motor oil in soil as influenced by plant treatment was monitored in a greenhouse study. Soil contaminated with used motor oil (1.5% w/w) was seeded with soybean (Glycine max)/green bean (Phaseolus vulgaris); sunflower (Helianthus annus)/Indian mustard (Brassica juncea); mixed grasses/maize (Zea

mays); and mixed clover (red clover, Trifolium pratense/ladino clover, Trifolium repens) and incubated. Extractable oil and grease remaining in the soil was monitored after 100 and 150 days. After 150 days in the clover treatment, the added oil was no longer detected. A total of 67% of the oil was removed in sunflower/mustard, and with addition of NPK fertilizer, the oil was completely removed.

Nabil M. Abdel-Jabba et.al. [55] have described that waste lubricating oil re-refining adsorption process by different adsorbent materials was investigated. Adsorbent materials such as oil adsorbent, egg shale powder, date palm kernel powder, and acid activated date palm kernel powder were used. The adsorption process over fixed amount of adsorbent at ambient conditions was investigated. The adsorption/extraction process was able to deposit the asphaltenic and metallic contaminants from the waste oil to lower values.

S. Rawat et.al. [56] discussed that solvent dewaxing of lubricating oil stocks with methyl ethyl ketone (MEK)-toluene mixture is well-known in the petroleum industry. Lubricating oil and wax stocks after solvent removal should not normally contain more than 50 and 150 ppm of toluene and 50 and 100 ppm of MEK, respectively. Determination of solvents in small quantities in these stocks is, therefore, necessary. The gas-liquid chromatographic (GLC) method devised for this purpose (1) uses a solvent-stripping manifold system consisting of a freeze-out trap at -50°C to retain solvents before they are flashed to the GLC column.

Harold Beuther et.al. [57] obtained that a process for converting untreated petroleum fractions to unusually stable, high viscosity index oils combined hydrogenation with controlled hydro cracking to gave high selectivity's to motor oil fractions. Yields are 10 to 50% greater than by solvent extraction. High yields of oils having viscosity indexes of 120 to 125 can be obtained from crudest. These new oils have very excellent colors and low carbon residue and sulfur contents regardless of their crude source.

Mithilesh Kumar Jha [58] suggests that lubricating oils are fluids such as engine oils, gear, hydraulic oils, turbine oils, etc., which are used to reduce friction between moving surfaces. They also serve to remove heat from working parts in machinery, remove wear debris, created by moving surfaces, and provide a protective layering on the metal surfaces to avoid corrosion. Lubricating oils are prepared by blending different viscosity-based oils with suitable proportion of additives. Base oils are either derived from crude oil or are synthetic material manufactured by chemical processes.

Manzoor.A. Khawaja et.al. [59] composed of toxic chemicals, such as heavy metals (which come from the additives and wear and tear of engine parts); together with water, combustion products, light hydrocarbons, mono and polyaromatic compounds, resinous material, carbon black and unused base oil. The used oil creates environmental pollution. Many methods for disposal of these hazardous wastes are in practice from previous decades. Dumping in the ground or pouring into sewers by individual producers, road oiling, and burning of oil as fuel are the oldest methods of waste oil disposal. But all these methods create air and water pollution.

Ranvir Singh et.al. [60] discussed that lubricating oil had wide range of applications. It's by far major application is in motor vehicles and engines where it is used to smoothen the functioning of engine parts and thereby improve the performance as well as extend the life of engine. Periodically, it has to be replaced at regular intervals because of contamination of oil caused by inclusion of wear and tear of metal parts in it. Worldwide, the earlier practice of dumping the contaminated oil after use poses many serious environmental problems.

H.Bridjanian et.al. [61] generated a process of thermal degradation. During normal use, impurities such as dirt, metal scrapings, water or chemicals can get mixed in with the oil or be generated in it due to thermal degradation or oxidation. Therefore, the oil quality gradually decreases to a level that the used oil should be replaced by a new one. Disposing the used oil off in nature creates an intense dangerous pollution. But by proper recovery and refinement of it, a lot of valuable product can be obtained.

A. James Spearot [62] oxidized newtonian oil phase and a dispersed insoluble particulate phase. The rheological behavior of such dispersions was investigated for insoluble concentrations from 0 to 23 wt %, shear rates from 20 to 140 second and temperatures from 20 to 80°C. Michaels and Bolger's constitutive equation for clay suspensions which assumes the existence of "flocs"-primary particles and entrapped water-also described the behavior under shear of the degraded oil samples. By analogy, the presence of particle aggregates consisting of insoluble oxidation products and an adsorbed oxidized oil fraction is postulated.

Farshid Owrang et.al. [63] investigated the oxidation of two different engine oils: a mineral and synthetic engine oil. The mineral oil was a CEC reference oil often used in the CEC fuel tests. The synthetic oil was biologically degradable often used for fuel tests. The oils were analyzed by liquid-state C NMR, 1H NMR and cyclic fast neutron activation analysis and were oxidized at about 550^0C at atmospheric pressure in an oxidizer with constant airflow.

A. Kamal et.al [64] have found that solvent extraction followed by adsorption to be one of the competitive processes for recycling of waste lubricating oil. He studied the performance of various solvents for sludge formation. 1-butanol produced maximum sludge followed by methyl ethyl ketone (MEK), 1-hexanol and 2-butanol. The difference in sludge formation between 1-butanol and MEK was only 0.3%. The extracted oil was then passed through a column of different adsorbents. A mixture of solvent and used lubricating oil was shaken in a 100 ml separating funnel to ensure adequate mixing. The sludge was allowed to settle at a constant temperature of 35°C in a thermostatic bath. After 24 hours, solvent-oil solution was separated from sludge. The sludge was dispersed twice with the same solvent to extract any remaining oil. The sludge was then dried till constant weight at 105°C. The washing solvent was mixed with solvent - oil solution. He found that no sludge formation takes place when hydrocarbons and MIBK were used. 2-butanol formed two liquid phases at room temperature (35°C) after 24 hours settling.

S. O. Ogbeide [65] carried out to study the recycling of spent engine oil as a result of indiscriminate disposal of the spent engine oil into the surrounding which has contributed immensely to the level of environmental pollution in our

society. He identified a unique method by which the spent oil is adequately recycled for reuse. The sample of spent engine oil is mixed with 70% concentration of sulphric acid in the ratio 10ml to 1ml and then heated to 60°C for one hour, and was allowed to settle for six hours so as to enable the insoluble mater and water remain to settle at the bottom of the beaker. The treated oil is decanted and sludge formed removed from the beaker. The treated oil is then contracted with activated carbon, and treated at 200°C – 250°C for 2-3 hours. The treated oil is filtered and allowed to cool. After which, the treated oil is analyzed.

CHAPTER - 3

MATERIALS AND METHODS

This chapter deals with the used lubricating oil, its characterization, the treatment methods, testing of very pertinent properties and the blending of additives to restore the quality of recycled lubricating oils in order to make it fit for further applications.

The samples of used lubricating oils were collected from Aligarh Auto Centre, Near New Bus Stand, Aligarh and Hero Honda Workshop, Marris Road, Aligarh. To carry out this research work, various solvents and chemicals of fine quality and purity were used. The main chemicals are n-Hexane, 2- Propanol, 1-Butanol, Keiselguhr, Sodium hydroxide Pellets, Conc. Hydrochloric acid, Fuller's Earth, Methyl ethyl ketone, Methyl iso butyl ketone, Conc. Sulphuric acid, Zincdithiophosphate, Molybdenum disulfide and Polyisobutylene.

3.1 EXPERIMENTAL METHODS

First of all the used lubricating oils from various sources were characterized in order to ensure their characteristics. For this purpose, these were subjected to various tests like flash point, ash content, viscosity and viscosity index, pour point, total acidity, inorganic acidity, saponification number and copper corrosion test.

3.1.1 Physico-Chemical Characteristics

The following physico-chemical characteristics have been studied during the present experimental research work:

3.1.1.1 Flash Point

Flash point is the lowest temperature at which application of test flame causes the vapour above the oil to ignite. Flash point measures the tendency of the fuel to form a flammable mixture with air under controlled laboratory conditions.

Procedure: The flash point of the samples (used engine oil, gear oil, compressor and hydraulic oils) was determined by using Cleveland (open) cup method. The sample was poured in the test cup. The temperature of the sample was increased fairly rapidly at the initial stage and then at a slow constant rate as the flash point of the sample approached (at specified intervals). After this, small test flame was passed across the cup. The lowest temperature at which application of the test flame caused the vapors above the surface of the liquid to ignite momentarily was taken as the flash point. It is very important property of a pet. product as it gives indication of vaporization. Higher flash point hydrocarbons/ pet. products catch the fire with difficulty when ignited. So it is important w.r.t. safety aspects.

3.1.1.2 Ash Content

Ash can result from oil, water-soluble metallic compounds, or extraneous solids, such as dirt and rust. The Knowledge of the amount of a product's ash forming material can provide information on whether the product is suitable for use in a given application.

Procedure: The silica crucible was heated at 800°C for 10 minutes and cooled to room temperature in a suitable container not containing a desiccating agent and weighted to the nearest 0.1 mg. The sufficient sample of oil was weighted into the crucible to give approximately 20 mg of ash .The sample in the crucible was heated until the contents became capable of being ignited with a flame and maintained at such a temperature to burn the sample at a uniform and moderate rate until only ash and carbon was left when the burning ceased. The residue was incinerated in a muffle furnace at 800°C until all carbonaceous material disappeared. Thereafter; it was cooled in the crucible to room temperature and weighed to the nearest 0.1 mg. The heating and weighing of crucible containing ash was repeated until consecutive weightings did not differ by more than 0.5 mg.

The weight of the ash was calculated as a percentage of the original of the sample as follows:

The ash percent (by weight) = 100 w/ W

Where; w = Weight in g of ash, and

W = Weight in g of sample

3.1.1.3 Viscosity and Viscosity Index

Kinematic viscosity is the measure of the resistance to gravity flow of a fluid. The pressure head is proportional to the density. The time of flow of a fixed volume of fluid is directly proportional to its kinematic viscosity. The unit of kinematic viscosity is stoke. Kinematic viscosity may be measured as an absolute property of the fuel, or alternately as a conventional property that is

dependent on the instrument and the method used. Viscosity index is the most widely used way of characterizing the effect of change of temperature on the viscosity of any oil.

Procedure: The viscosity index was calculated by Redwood Viscometer No.1. It comprises a sample cup fitted with a standard-sized orifice in the base and surrounded by a water jacket containing a heating device. When the temperature reaches the test level, the orifice is unsealed a heating device. When the temperature reaches the test level, the orifice is unsealed and the time of flow is determined for 50ml volume of the sample. The viscosities of lubricating oils were determined by Red Wood Viscometer No.1 at 40°C and 100°C .Viscosity index were calculated by the following formula:

Viscosity index = [L-U/L-H] ×100

Where; L = Kinematic viscosity at 40°C of an oil of 0 viscosity index

U = Kinematic viscosity at 40°C of the oil whose viscosity index is to be calculated.

H = Kinematic viscosity at 40°C of an oil 100 viscosity index

3.1.1.4 Pour Point

Pour point is a well-established test to estimate the temperature at which a sample of oil becomes sufficiently solid to prevent its movement. It is the lowest temperature expressed in multiple of 3°C at which the oil is observed to flow when cooled and examined under prescribed conditions. The pour point

temperature depends to a large extent on the thermal history of the sample. Also, the pour point indicates the waxy nature of the oils.

Procedure: The pour point of the lubricating oils, are important properties related with the flow of lube oil. The oil sample was poured into the test jar to the specified level and closed with the cork fitted with the thermometer. The position of the cork and thermometer was adjusted so as the cork was fitted in tightly and the thermometer and the jar were coaxial, moreover, the thermometer bulb was immersed so that the beginning of the capillary was 3 mm below the surface of the oil. The disk was placed in the bottom of the jacket and ring gasket around the test jar, 25mm above the bottom. The disc, gasket, and inside of the jacket should be clean and dry. The test jar was inserted in the jacket. The bath temperature was maintained at -1°C to +2°C. After the oil was cooled enough to allow the formation of paraffin wax crystals, great care is to be taken to disturb the mass of the oil nor permit the thermometer to shift in the oil; Any disturbance of the spongy network of wax crystals, will lead to low and fictitious results. Beginning at a temperature 9°C above the expected pour point in case of oils with pour point above 39°C and for other oils at a temperature 12°C above the expected pour point, at each test thermometer reading which was a multiple of 3°C, the jar was removed from the jacket carefully and was tilted enough to ascertain whether there was a movement of the removal and replacement should not take more than 3 seconds. If the oil has not ceased to flow when it has been cooled to 9°C, the test jar has to be transferred to another jacket in a second bath maintained at a temperature of -18 to -15°C. If the oil has not ceased to flow when it has been cooled to -6°C , the jar has to be transferred to another jacket in a third bath maintained at a temperature range of -35 to -32°C. The test is continued in this manner until a point reached at which

the oil in the test jar shows no movement when the test jar was held in a horizontal position for exactly 5 seconds. The accurate temperature with the help of the test thermometer was recorded and 3°C was added to this temperature as the pour point.

3.1.1.5 Total Acidity

New and used petroleum products may contain acidic constituents present as additives or as degradation products, such as oxidation products, formed during service. Total acidity is a measure of the combined organic and inorganic acidity. Total acidity is an indication of the corrosive properties of the product.

Procedure: In total acidity, toluene 60 ml and alcohol 40 ml were neutralized using alkali-blue solution as an indicator with alcoholic potassium hydroxide (KOH) solution. This mixture was added to approximately 10 g of sample was completely dissolved until the colour of the mixture turned purple blue. It was titrated with KOH and at the end-point, the purple blue colour changed to red colour comparable to that of 10 % solution of cobalt nitrate. The total acidity was calculated from the following formula:

$$A_T = 56.1 [N \times V] / W$$

Where; A_T = Total acidity in mg potassium hydroxide / g of sample

V = Volume of potassium hydroxide solution in ml,

N = Normality of the potassium hydroxide solution,

W = Weight of sample in g

3.1.1.6 Inorganic Acidity

Inorganic acidity is a measure of the mineral acid present. Organic acidity is obtained by deducting the inorganic acidity from the total acidity.

Procedure: 25 g of the sample was diluted with 75 ml toluene and thereafter 100 ml boiled distilled water was added. The mixture was then heated for 15 min followed by cooling. The inorganic acidity was calculated from the following formula:

$$\text{Inorganic Acidity} = 4.5 \times N \times T$$

Where; N = Normality of potassium solution,

T = Volume of potassium hydroxide solution in ml

3.1.1.7 Saponification Number

Procedure: A known weight of the sample was dissolved in 25 ml methyl ethyl ketone and heated for 30 min with 25 ml of 0.1 N alcoholic potassium hydroxide. Thereafter, 50 ml of naphtha was added immediately and the solution was titrated with 0.1N hydrochloric acid using neutralized phenolphthalein as indicator. The blank reading was taken without using oil sample. The saponification value was calculated from the following formula:

$$\text{Saponification Number} = 56.1\ N\ (V_1 - V_2) / W$$

Where; N = Normality of the hydrochloric acid,

V_1 = Volume in ml of acid used in titrating blank,

V_2 = Volume in ml of acid in titrating the sample,

W = Weight of the sample in grams

3.1.1.8 Copper Corrosion Test

Petroleum products contain sulphur compounds, most of which are removed during refining. Of the sulphur compounds remaining in the petroleum products, however, some can have a corroding effect on various metals. The corrosivity is not necessarily directly related to the total sulphur content. The effect can vary according to other chemicals and types of sulphur compounds present. This test serves as a measure of possible difficulties with copper, brass or bronze parts of the fuel systems.

Procedure: A cleaned and smoothly polished copper strip is immersed in a given quantity of sample, which is then maintained at the specified temperature for the specified length of time. The strip is removed from sample, washed with aromatic and sulphur free petroleum spirit and examined for evidence of etching, pitting or discolouration it is then compared with ASTM copper-strip corrosion standard colour code. The classification code indicates that the numbers 1, 2, 3 and 4 designate slight tarnish, moderate tarnish, dark tarnish and corrosion, respectively.

3.2 RECLAMATION OF USED LUBRICATING OILS

Used lubricating oils were collected from different local garages and service stations in Aligarh city and mixed in a single container. Used lubricating oil was stored for seven days to allow large suspended particles to settle under gravity. As the samples were obtained from many locations, it was assumed that it could represent a typical feedstock for recycling the used lubricating oil. Used

oils (engine, gear, compressor and hydraulic) were regenerated by physical as well as chemical methods e.g. dehydration, solvent treatment, clay treatment and filtration. Different additives were blended in sufficient amount to prepare finished oils of different grades. The whole procedure of the regeneration of used oils has shown in a flow diagram.

3.2.1 Reclamation of Used Engine Oils

3.2.1.1 Dehydration

Used engine oils were taken in a two-necked round bottom flask equipped with arrangements for heating and stirring under vacuum. The used lubricating oils were heated at 100°C for one hour to remove water. After dehydration, the temperature was raised to 250°C to remove light ends and after their removals; the dehydrated oils were allowed to cool to room temperature and filtered.

3.2.1.2 Solvent Treatment

The dehydrated oils thus obtained were then solvent treated with 1-butanol using 50 percent and 60 percent (v/v) at room temperature with constant stirring for 30 min. and centrifuged. The solvent treated oils were also allowed to settle over night after 24 h, solvent sludge was removed and supernatant solvent treated oils were recovered.

3.2.1.3 Clay Treatment and Filtration

To prepare different samples, the solvent treated oils were heated under vacuum with constant stirring to 100°C and the fuller's earth was added in 8 to 10 percent (w/v) for 50 and 60 percent solvent treated oils and then the temperature

was raised to the bleaching temperature (250°C, 280°C and 300°C). Thereafter, the clay treated oils were allowed to cool and filtered.

3.2.2 Reclamation of Used Gear Oils

3.2.2.1 Dehydration

Used gear oils were subjected to dehydration for removal of water at 100°C under vacuum with constant stirring for one hour and then allowed to cool to room temperature and then filtered.

3.2.2.2 Solvent Treatment

The dehydrated oils thus obtained were then solvent treated with 1-butanol solvent using 30 to 50 percent (v/v) at room temperature with constant stirring for 30 min. The solvent treated oils were allowed to settle overnight. After 24 h solvent sludge was removed and supernatant solvent treated oils were recovered.

3.2.2.3 Clay Treatment and Filtration

Solvent treated oils were heated under vacuum to 100°C and the fuller's earth was added in 4 to 6 percent (w/v). The temperature was raised to 300°C for 30 min then cooled and filtered.

3.2.3 Reclamation of Used Compressor Oils

3.2.3.1 Dehydration

Used compressor oils were dehydrated at 100°C for removal of water under vacuum with constant stirring for 1 h, thereafter; the oil was allowed to cool at room temperature and filtered to remove impurities.

3.2.3.2 Solvent Treatment

Dehydrated oils thus obtained were solvent treated with 1-butanol using solvent 30 to 40 percent (v/v) at room temperature with constant stirring for 30 min. The solvent treated oils were then allowed to settle overnight. After 24 h, solvent sludge was removed and supernatant solvent treated oils were recovered.

3.2.3.3 Clay Treatment and Filtration

Solvent treated oils were heated under vacuum to 100°C and the fuller's earth was added in 4 to 6 percent (w/v). The temperature was raised to 200°C and the oil was bleached at this temperature for 30 min. After bleaching, the oil was cooled and filtered.

3.2.4 Reclamation of Used Hydraulic Oils

3.2.4.1 Dehydration

Used hydraulic oils were subjected to dehydration for removal of water at 100°C under vacuum with constant stirring for 1h and then allowed to cool to room temperature and filtered.

3.2.4.2 Solvent Treatment

Dehydrated oils thus obtained were then solvent treated with 1-butanol using solvent 30 to 50 percent (v/v) at room temperature with constant stirring for 30 min. The solvent treated oils were allowed to settle overnight. After 24 h, solvent sludge was removed and supernatant solvent treated oils were recovered.

3.2.4.3 Clay Treatment and Filtration

Solvent treated oils were heated under vacuum with constant stirring to 100°C and the fuller's earth was added in 4 to 6 percent (w/v). The temperature was raised to 250°C and the oil was bleached at this temperature for 30 min and then cooled thereafter, the oil was filtered.

3.2.5 Blending of Additives

Different percentages of additives were blended in such proportion which could result in yielding the reclaimed and blended lubricating oils so as they meet their respective Indian specification. Sufficient amount of Zincdithiophosphate, Polyisobutylene and Molybdenum disulfide was blended in suitable base stocks to prepare different mono and multigrade of engines oils for automotive purposes.

3.2.6 Percent Sludge Removal

The percent sludge removal represents the quantity of dry sludge removed from the used oil after mixing with solvent. The sample of used oil is mixed with the solvent in a test tube for 25 minutes under continuous stirring (400- 430 r.p.m.).

The steps consist of removing the sludge from the bottom of the settling flask after the settling period has lapsed into a weighted glass tube. First the separated sludge is redispersed by adding 10 cm^3 of 2- propanol which immediately produces large flakes. After 24 hr of gravity settling, the liquid is discarded using vacuum filtration and the bottom sludge cake was collected. The washed sludge is then placed in to an oven for 20 minutes at 100^0C for drying purposes. The hot dry sludge is then cooled to room temperature and weighted W_2. The percent of sludge removal can then be calculated as follows.

$$PSR = W_2 / W \% \qquad (1)$$

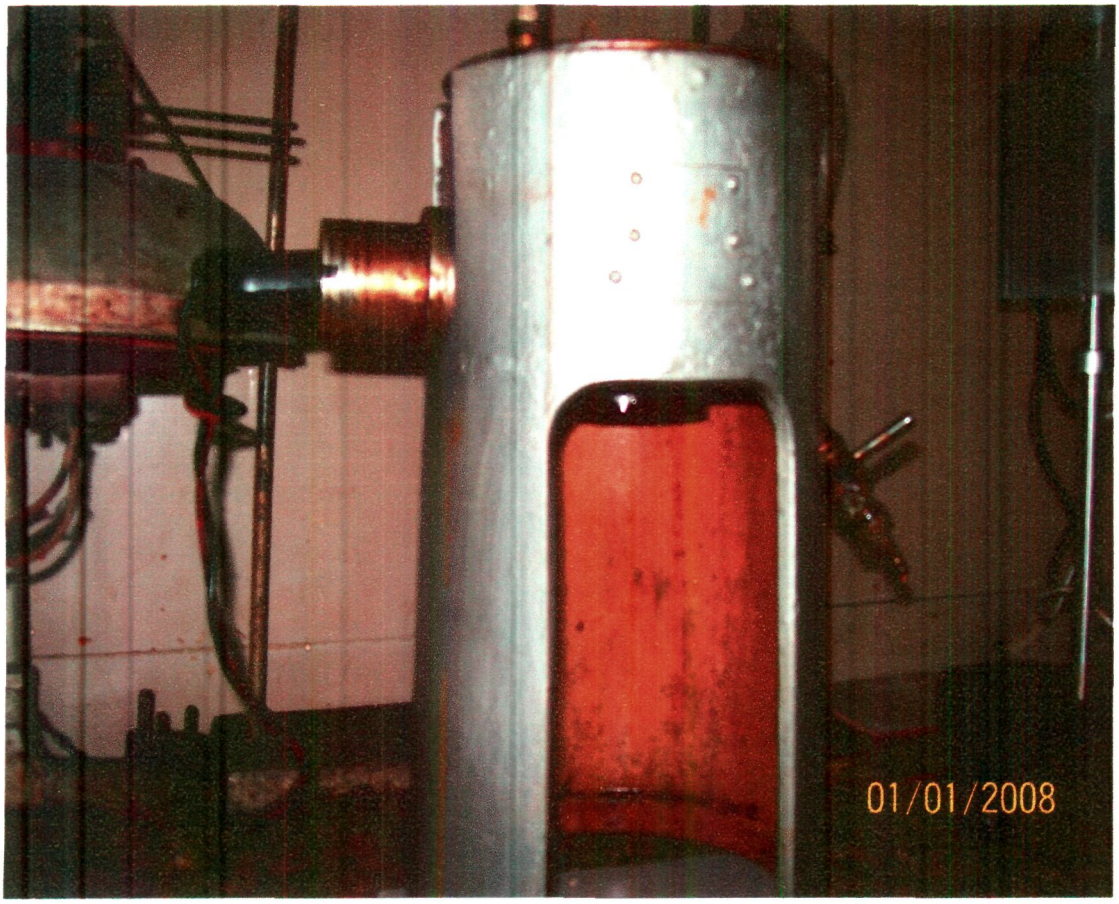
Where W is the mass of used oil in the solvent/oil mixture.

3.2.7 Percentage Oil Losses

The oil loss represents the amount of oil that did not dissolved in the solvent but rather settles with the sludge but rather settles with the sludge. Percent oil loss is defined as the amount of oil in sludge phase per 100 grams of used oil. This factor was calculated from the same washing process stated above and calculated as follows.

$$POL = (W_1 - W_2) / W \% \qquad (2)$$

3.3 EQUIPMENTS USED IN RECLAMATION OF LUBRICATING OILS



[Redwood Viscometer]

Manufactured by: S.M. Scientific Instruments (P) Ltd, Delhi-92

[Redwood Viscometer]

Manufactured by: S.M. Scientific Instruments (P) Ltd, Delhi-92

[Cleveland (Open) Cup]

Manufactured by: D. K. Scientific Industries, Ahmedabad, Gujarat,

[Colorimeter]

Manufactured by: R. K. Scientific & Engineering Works, Roorkee

[Portomin Deluxe Centrifuge]

Manufactured by: R. K. Scientific & Engineering Works, Roorkee

[Copper Strip Corrosion Apparatus]

Manufactured by: Petroleum Instruments (India) Pvt. Ltd., Calcutta - 13

[Oven]

Manufactured by: S.M. Scientific Instruments (P) Ltd, Delhi-92

[Motorized Oil Test]

Manufactured by: Rectifiers and Electronics Instruments Pvt. Ltd., New-Delhi

[Rust Preventive Tester]

Manufactured by: Petroleum Instruments (India) Pvt. Ltd., Calcutta - 13

[Experimental Set-up]

3.3.1 Parts of experimental set-up

Apparatus - The experimental apparatus consisted of a glass flask heated by suitable means and provided with a reflux condenser discharging into a trap and connected to the flask. The connections between the trap and the condenser and the flask should be interchangeable ground glass joints. The trap serves to collect and measure the condensed water and to return the solvent to the flask. The various components are described below:

a) ***Flask*** - A 250 to 500 ml flasks made of hard resistance glass, well annealed was used during this research work.

b) ***Condenser*** - A glass made water - cooled reflux type condenser was used during this research work.

Socket - 24/29

Cone - 24/29

Effective length - 200 mm

c) ***Receivers Adapter*** - otherwise called the trap, made of hard resistance glass, well annealed provided with ground glass joints.

Socket - 24/29

Cone - 24/29

d) ***Thermometer Mercury filled*** - Range 0- 360°C

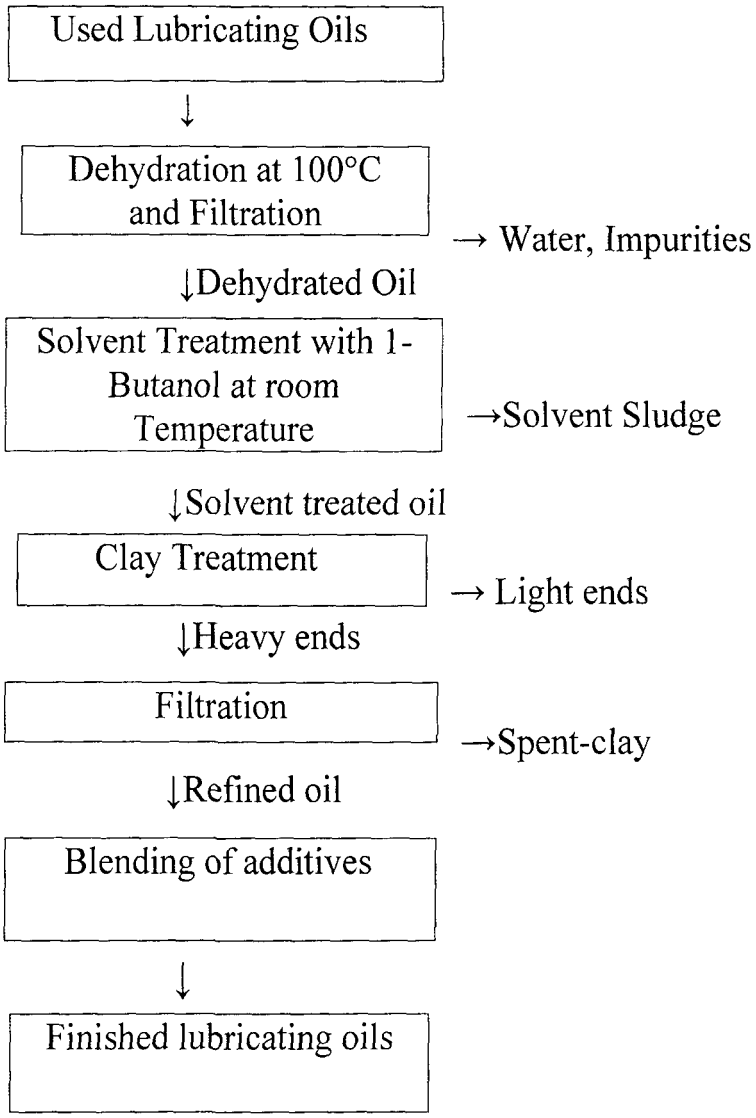


Fig 3.1 Flow diagram of Reclamation of Used Lubricating Oils

CHAPTER - 4

RESULTS AND DISCUSSION

This chapter deals with the experimental results obtained from the study of characterization of used lubricating oils, dehydration, solvent extraction and clay treatment. The used lubricating oils were tested to find out their characteristics and the best solvent for treatment purpose with respect to sludge removal and oil losses.

4.1 CHARACTERISTICS OF USED LUBRICATING OILS

The characteristics of various samples of used lubricating oils i.e., engine oils, gear oils, compressor oils and hydraulic oils, used in the present work are reported in Table 4.1, 4.12, 4.18 and 4.22 respectively.

4.1.1 Used Engine Oils

The experiments were performed on 23 samples of used lubricating oils. Table 4.1 shows the characteristics of ten different samples of used engine oils obtained from various sources. The colour of the used engine oils being black; and the ash content in these samples varied from 1.18 to 2.80 %. This variation may be due to difference in the percentage of additives which would have been initially added to the base stock of these engine oils. The flash point of different used engine oils varied from 108°C to 192°C. As the sources of the used engine oils were not the same, the water content and viscosity of the different engine oils were in the range of 0.5 to 4.0 % and 32.5 to 92.5 cst at 40°C, respectively.

The difference in viscosity is most probably due to change in additive's composition and base stock as well. The processing of generated data has revealed certain pertinent and interesting facts from this experimental study. The effect of solvents in extraction process, dehydration, clay treatments of refined lubricating oils along with possible reasons, have been discussed here.

Table 4.1 Characteristics of Used Engine Oils

Property/test	E_1	E_2	E_3	E_4	E_5	E_6	E_7	E_8	E_9	E_{10}
1. Colour	Black	Black	Black	Black	Black	Black	Black	Black	Black	Black
2. Viscosity (cst) at 40°C	32.5	38.5	42.0	36.0	41.0	41.5	42.0	48.0	71.0	92.5
3. Flash Point (°C)	108	112	118	120	123	125	130	140	180	192
4. Ash Content (%)	2.65	1.18	2.46	1.48	2.14	2.78	2.80	2.46	2.50	2.10
5. Water Content (%)	2.5	3.5	1.8	1.0	4.0	1.6	3.8	3.2	1.0	0.5

4.1.2 Used Gear Oils

Table 4.12 shows the characteristics of five different types of used gear oils obtained from various sources. The ash content of used gear oils was less in comparison to used engine oil, being in the range of 0.5 to 1.0 % which is perhaps due to less quantity of additives used for gear oils than that for used engine oils. The flash point observed for different used gear oils varied between 215°C to 235°C while pour point varied from -6°C to -12°C. As the sources of the used gear oils were different, the water content and viscosity of the different oils were found to vary in the range of 0.5 to 12.0 %, and 160.0 to 335.0 cst at 40°C, respectively. The difference in viscosity may perhaps be due to change in base stock.

Table 4.12 Characteristics of Used Gear Oil

Property/test	Types of Used Gear Oils				
	G_1	G_2	G_3	G_4	G_5
1. Colour	Green	Radish Brown	Green	Brown	Dark Brown
2. Viscosity (cst) at 40°C	160	210	235	280	335
3. Flash Point (°C)	215	218	223	230	235
4. Pour Point (°C)	-9	-11	-12	-7	-6
5. Ash Content (%)	0.5	1.0	0.5	0.8	0.5
6. Water Content (%)	0.5	0.5	1.0	0.5	0.5

4.1.3 Used Compressor Oils

Table 4.18 shows the characteristics of three samples of used compressor oils obtained from various sources. As the used compressor oils contained very low percentage of additives, the ash content was expected to be lower and was expected to be lower and was observed to be in the range of 0.02 to 0.04 % . The colour of various used compressor oils was either yellowish or brownish. The flash point of the different used compressor oils varied from 162°C to 172°C. Further , the water content , viscosity and pour point of the different samples of used compressor oils were found to vary in the range of 1.8 to 2.3%, 37.0 to 65.5 cst at 40°C and -31°C to -27°C, respectively, due to difference in the source of used compressor oils. The difference in various properties may perhaps be due to change in base stock.

Table 4.18 Characteristics of Used Compressor Oils

Property/test	Types of Used Compressor Oils		
	C_1	C_2	C_3
1. Colour	Brown	Yellow	Brown
2. Viscosity (cst) at 40°C	37.0	45.5	65.5
3. Flash Point (°C)	162	168	172
4. Pour Point (°C)	-31	-29	-27
5. Ash Content (%)	0.02	0.02	0.04
6. Water Content (%)	2.1	1.8	2.3

4.1.4 Used Hydraulic Oils

Table 4.22 shows the characteristics of five different samples of used hydraulic oils obtained from various sources. The colour of the various used hydraulic oils was yellow / dark yellow / brown. The flash point of the different used hydraulic oils varied from 190°C to 224°C and the pour point -8°C to -3°C. Since the source of the used hydraulic oils were different, the water content and viscosity of the different oils were found to be different and these were in the range of 1.5 to 2.2 % and 48.0 to 340.0 cst at 40°C, respectively. The difference in various properties may perhaps be due to change in composition of base stocks.

Table 4.22 Characteristics of Used Hydraulic Oils

Property/test		Types of Used Hydraulic Oils				
		H_1	H_2	H_3	H_4	H_5
1.	Colour	Yellow	Yellow	Dark Yellow	Brown	Dark Yellow
2.	Viscosity (cst) at 40°C	48	74	125	230	340
3.	Flash Point (°C)	190	210	220	218	224
4.	Pour Point (°C)	-8	-5	-5	-3	-5
5.	Ash Content (%)	0.7	0.7	0.9	1.0	1.2
6.	Water Content (%)	2.1	1.8	1.5	2.2	1.8

4.2 DEHYDRATION OF USED LUBRICATING OILS

The technique of dehydration as explained in Chapter-3, Materials and Methods was employed for removal of water present in the used lubricating oil samples. Initially few samples of used engine oils were dehydrated to remove water as well as light ends in dehydration process and then filtered. However, later processing of using clay treatment, it was observed that the process of removal of lower fraction at this stage is not prudent since the clay treatment was observed to be effective only at higher temperatures and the simultaneous removal of lower fraction during the process of bleaching was found to be more economical. Table 4.1 shows that different types of used engine oil contained different percentage of water .The range of water content present in used engine oils varied from 0.5 to 4.0 %; different types of used gear oils contained water in the range of 0.5 to 1.0 % (Table 4.12); Table 4.18 shows that different types of used compressor oils contained water content in the range of 1.8 to 2.3 %; While different types of used hydraulic oils contained water content in the range of 1.5 to 2.2 % (Table 4.22). It can be concluded that water content in used lubricating oils vary between 0.5 to 4.0 %.

4.3 SOLVENT TREATMENT OF DEHYDRATED USED LUBRICATING OILS

The dehydrated samples of used lubricating oils were further treated by solvents. The nature and properties of solvents play an important role in a solvent extraction process. The collected samples were treated with four solvents; namely 1-butanol, 2- propanol, Methyl ethyl ketone and Methyl iso butyl ketone at various temperatures. The oil losses (%) and sludge removal (%)

were determined in four solvent treatments. The results so obtained have been used to plot the graphs for analysis purpose. This is quite evident from Fig. 4.1 through Fig. 4.20. The solvent treatment offered by 1- butanol was the best with respect to percent sludge removal. Therefore, it was decided to carryout the further experiments with 1- butanol only. It is true for all the samples of used lubricating oils.

4.3.1 Used Engine Oils

In the solvent refining of dehydrated engine oils 50 and 60 % (v/v) of 1-butanol was used because below this concentration, proper settling of solvent was not achieved. It may be due to the presence of higher percentage of additives and contaminants present in the used lubricating oils. Although, the settling time was slightly higher even for 50 % 1-butanol treated oils but at the same time the yield was found to be better. Further, there was no improvement in the yield of solvent treated lubricating oil above 60 % of 1-butanol. Therefore, the solvent treatment was performed only by 50 and 60 % 1-butanol. The yield of solvent treated used lubricating oils varied for different types of used engine oils. The variation in yield was due to the break down of additives and carbonaceous matter present in used oils.

4.3.2 Used Gear Oils

In case of dehydrated used gear oils, 30 to 50 % (v/v) of 1- butanol was used for solvent refining. Below 30 % of solvent level, the settling time was very high. Therefore, in further experiments the solvent level below 30 % was not studied. The yield of solvent treated used lubricating oils varied for different types of used gear oils and was observed to be in decreasing order for the oils treated

with 30, 40 and 50 % 1-butanol. Above 50 % of solvent treatment was not performed. The yield of solvent treated gear oils was observed to be better than that of the engine oil which is due to the lesser amount of additives present in the gear oils.

4.3.3 Used Compressor Oils

Similarly the dehydrated compressor oil samples of 30 to 40 % (v/v) of 1-butanol were used to study solvent refining. Below this percentage of solvent, proper settling was not achieved. The settling time was slightly higher for 30 % 1-butanol treated oil as compared to 35 and 40 % 1-butanol treated oils but the yields were excellent. Therefore, the oils treated with 30 to 40 % solvent were considered suitable for further studies. The yield of solvent treated oils was observed to vary for different types of used compressor oils. There was no further improvement in the yield of solvent treated compressor oil by using more than 40 % of solvent. Therefore, the solvent treatment was not performed above this concentration.

4.3.4 Used Hydraulic Oils

Lastly dehydrated hydraulic oil samples were treated with 25 to 35 % (v/v) of 1-butanol for solvent refining. Below 25 % of 1-butanol, proper settling was not achieved; therefore, the treatment was not done below this concentration. Further, the settling time was although slightly higher for 25 % solvent treated used lubricating oil but the yield was exceptionally good. The settling and yield for oils treated with 30 and 35 % solvent were also observed to be good. However, there was no further improvement in the yield of solvent treated oil by using more than 35 % of 1-butanol. Therefore, the solvent treatment was not

performed above this percentage of solvent and 25 to 35 % solvent level was considered to be suitable for further studies. The yield of solvent treated oils was observed to vary for different types of used hydraulic oils.

Fig. 4.1 has shows the effect of ratio of solvent to oil on the percent oil losses when 1-butanol is used at various temperatures. This ratio increases from 0.8 to 5.5, the percent oil losses decreases from 17.5 to 15.4%. It represents the oil losses in sludge phase achieved at various extraction temperatures ranging from 20°C to 52°C. The data are well correlated with ±5.02% deviation which is acceptable limit.

Fig. 4.2 shows the effect of ratio of solvent to oil on the percent oil losses when 2- propanol is used at various temperatures. This ratio increases from 1.3 to 5.5, the percent oil losses decreases from 17.2 to 13.9%. It represents the oil losses in sludge phase achieved at various extraction temperatures ranging from 20°C to 52°C. The data are well correlated with ±23.17% deviation which is acceptable limit.

Fig. 4.3 explains behavioral the effect of solvent to oil ratio on the percent oil losses when Methyl ethyl ketone is used with at various temperatures. This ratio increases from 2.5 to 7.5, the percent oil losses decreases from 10.3 to 8.3%. It represents losses in sludge phase achieved at various extraction temperatures ranging from 20°C to 52°C. These data are well correlated by the equations given there. The experimental data deviate from the normal trend within with ±6.04% deviation which is acceptable limit.

Fig.4.1 The effect of solvent to oil ratio on the extraction performance of 1- butanol at various temperatures

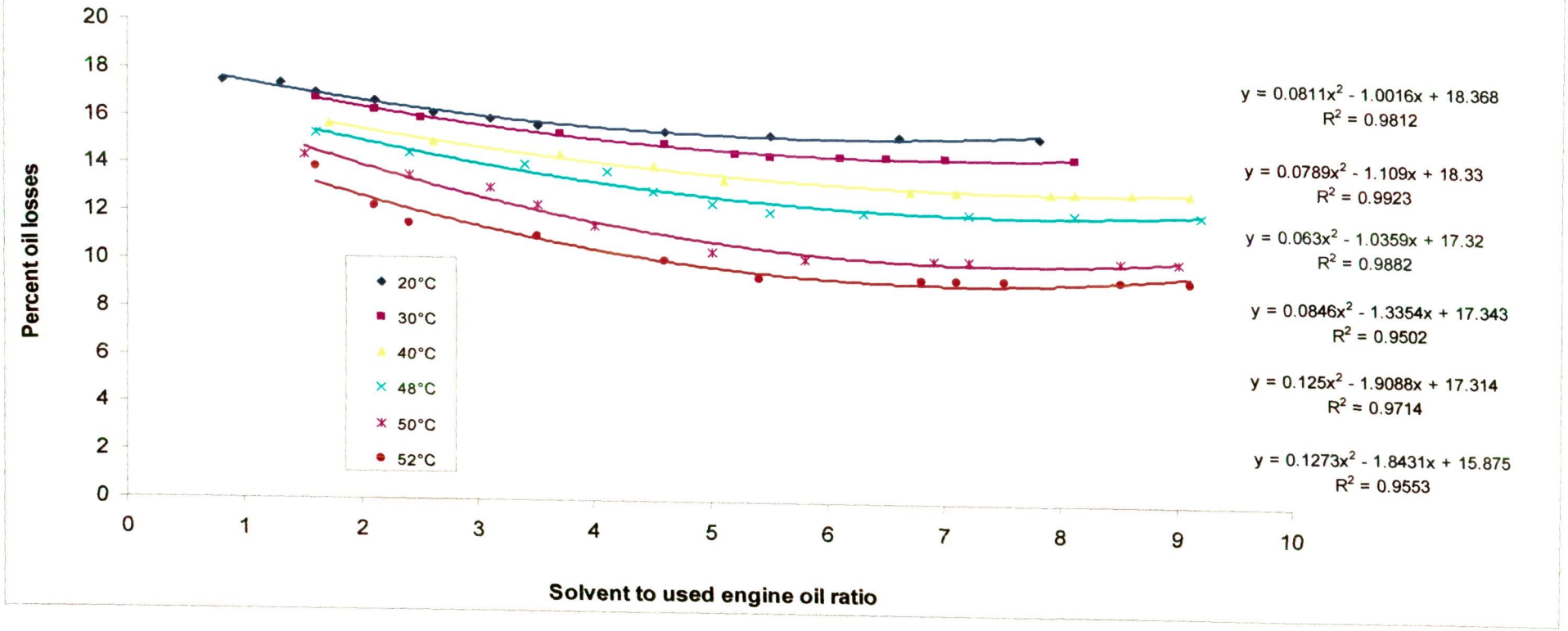


Fig.4.2 The effect of solvent to oil ratio on the extraction performance of 2-propanol at various temperatures

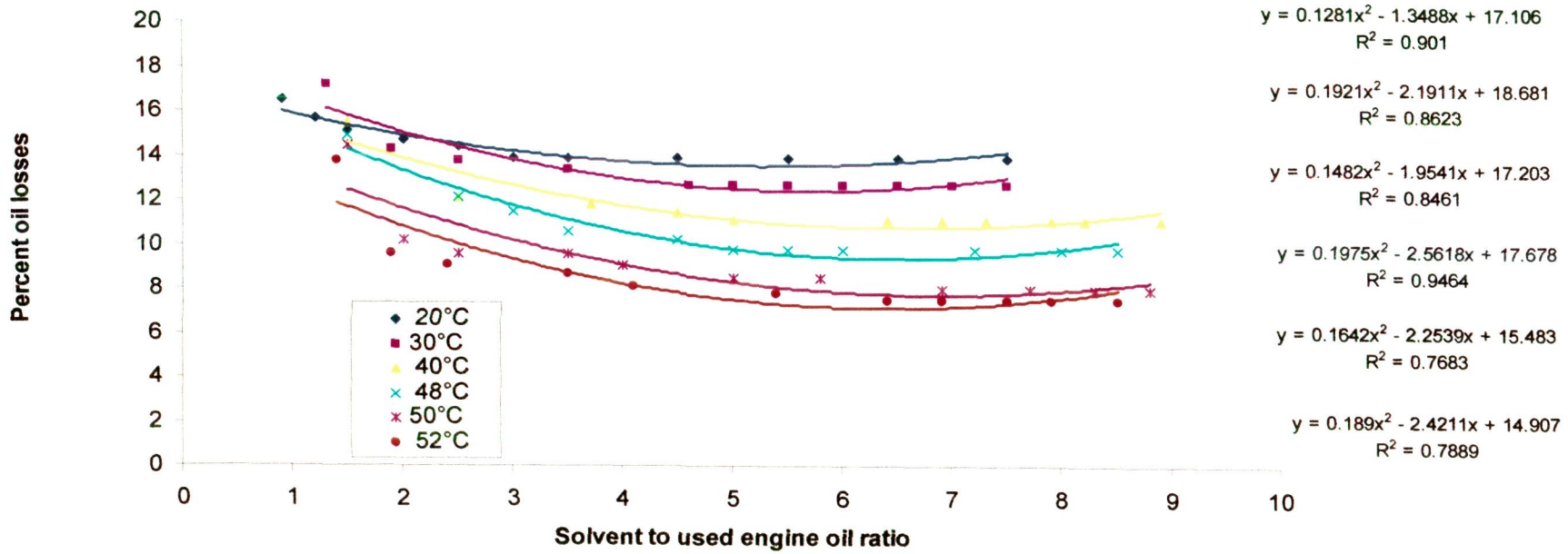
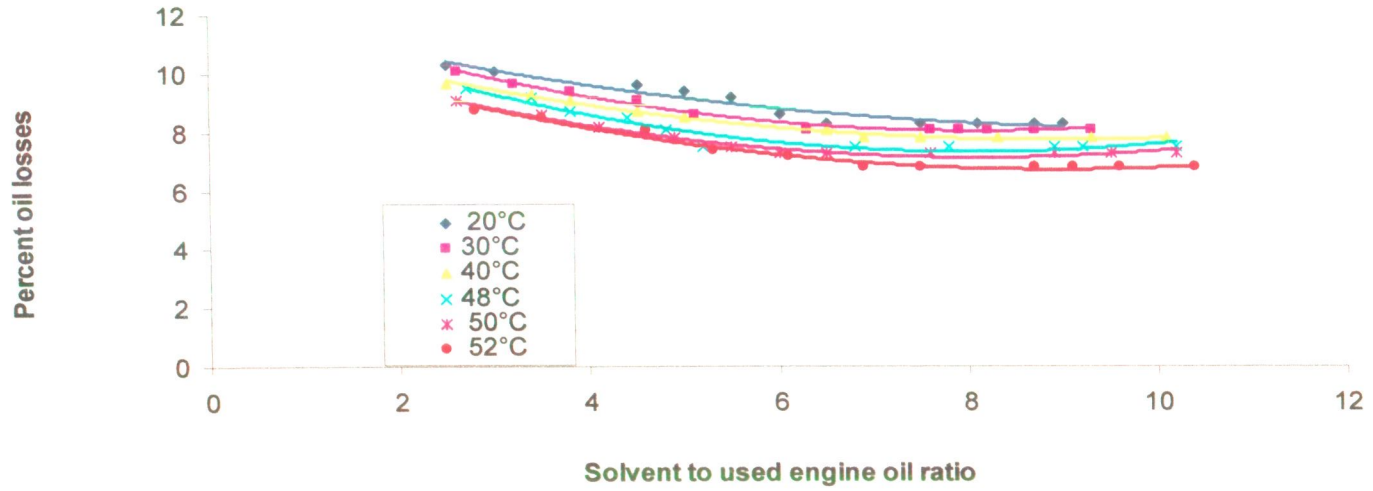


Fig.4.3 The effect of solvent to oil ratio on the extraction performance of Methyl ethyl ketone at various temperatures



$y = 0.0399x^2 - 0.8012x + 12.178$
$R^2 = 0.9398$

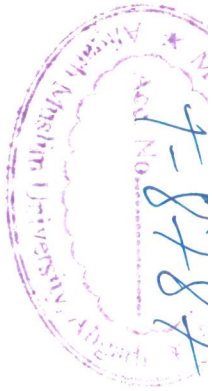
$y = 0.0693x^2 - 1.123x + 12.6$
$R^2 = 0.987$

$y = 0.0497x^2 - 0.884x + 11.675$
$R^2 = 0.9911$

$y = 0.0766x^2 - 1.2359x + 12.314$
$R^2 = 0.9392$

$y = 0.0643x^2 - 1.0444x + 11.387$
$R^2 = 0.9798$

$y = 0.0578x^2 - 1.0342x + 11.36$
$R^2 = 0.9744$



Similarly, the effect of ratio of solvent to oil on the percent oil losses when Methyl iso butyl ketone is used at various temperatures as seen in Fig. 4.4. As this ratio increases from 1.3 to 5.5, the percent oil losses decreases from 17.2 to 13.9%. A significant drop of percent oil losses is observed. It represents the oil losses in sludge phase achieved at the various temperatures (20°C to 52°C) in solvent extraction process. These plots provide the correlations with various R^2 values. This varies in the range of 0.7683 to 0.9576 which is within limit of tolerance. The results of Figs.4.1 to 4.4 conclude that lowest temperature (20°C) offers best performance of oil losses in this solvent extraction process.

In Fig. 4.5 the percent oil losses in this study with four solvents at 20^0C are illustrated. As seen in the figure, the two solvents (1-butanol, 2-propanol) gave almost similar percent oil losses as solvent to oil ratio increases. In figure 4.5, MIBK and MEK also gave almost similar percent oil losses as solvent to oil ratio increases. However, as solvent to oil ratio increases, the difference slightly increases. These data are well correlated by the equations given there. The experimental data deviate from the normal trend within with ±9.90% deviation which is acceptable limit.

In Fig. 4.6 the percent oil losses in this study with four solvents at 30^0C are illustrated. As seen in the figure, the two solvents (1-butanol, 2-propanol) gave almost similar percent oil losses as solvent to oil ratio increases. In figure 4.6, MIBK and MEK also gave almost similar percent oil losses as solvent to oil ratio increases. However, as solvent to oil ratio increases, the difference slightly increases. These data are well correlated by the equations given there. The experimental data deviate from the normal trend within with ±15.77% deviation which is acceptable limit.

Fig.4.4 The effect of solvent to oil ratio on the extraction performance of Methyl iso butyl ketone at various temperatures

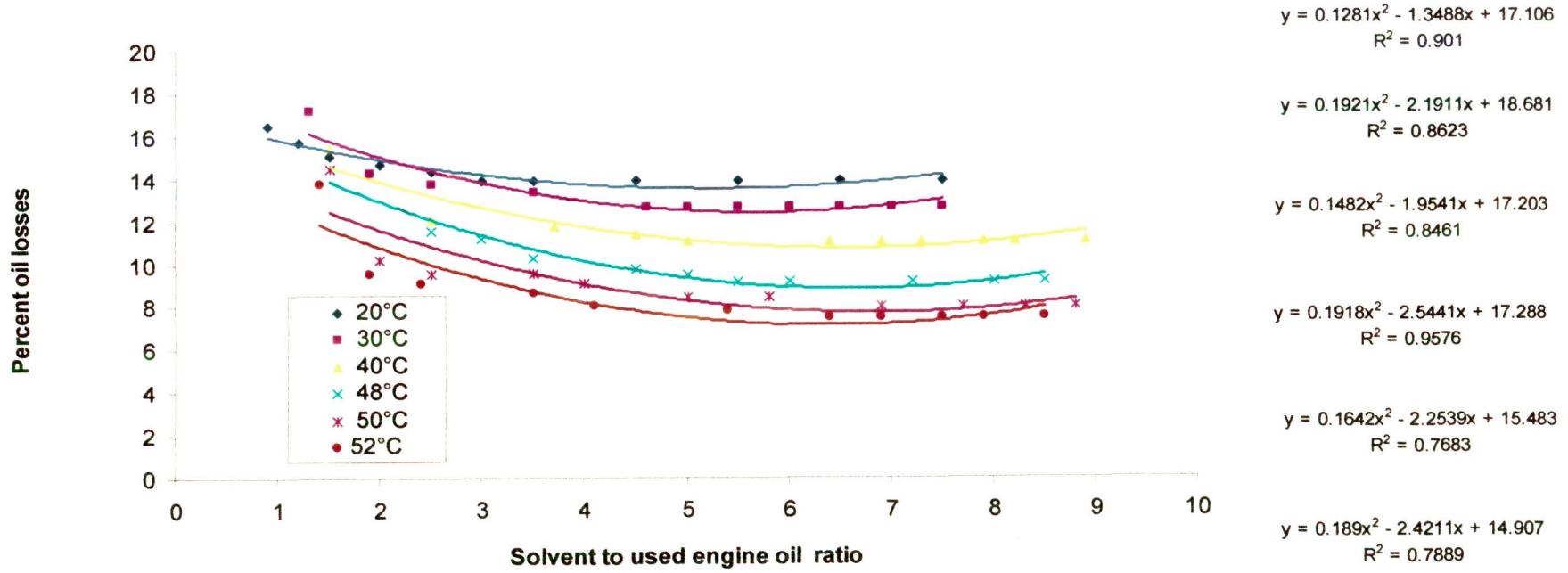
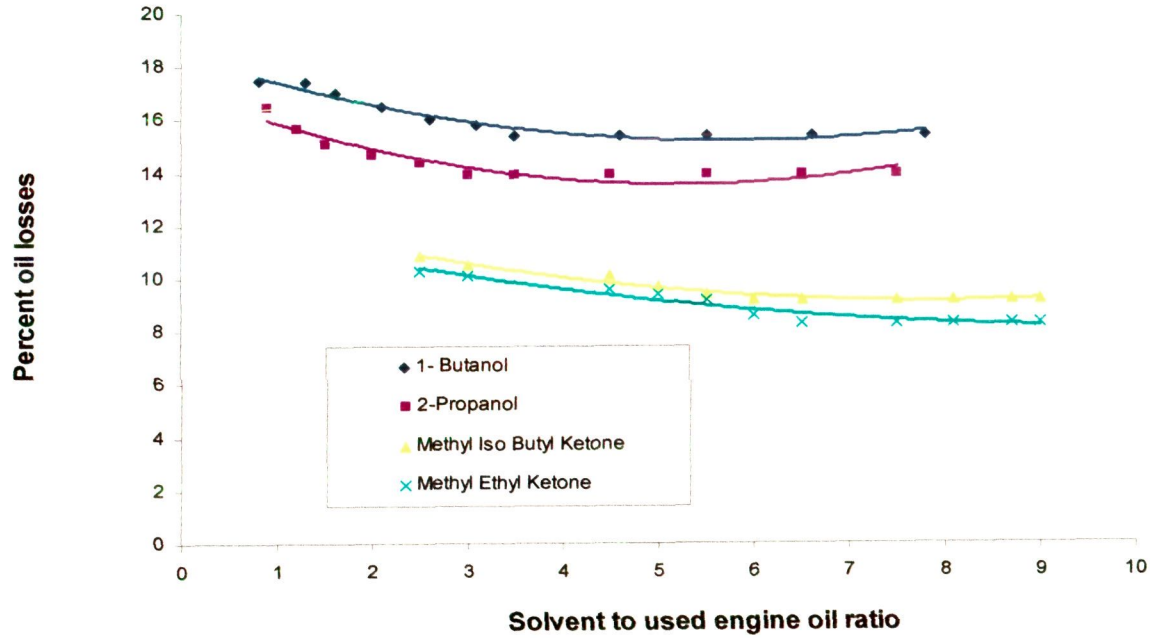


Fig.4.5 Percent oil losses in extraction by various solvents at 20°C



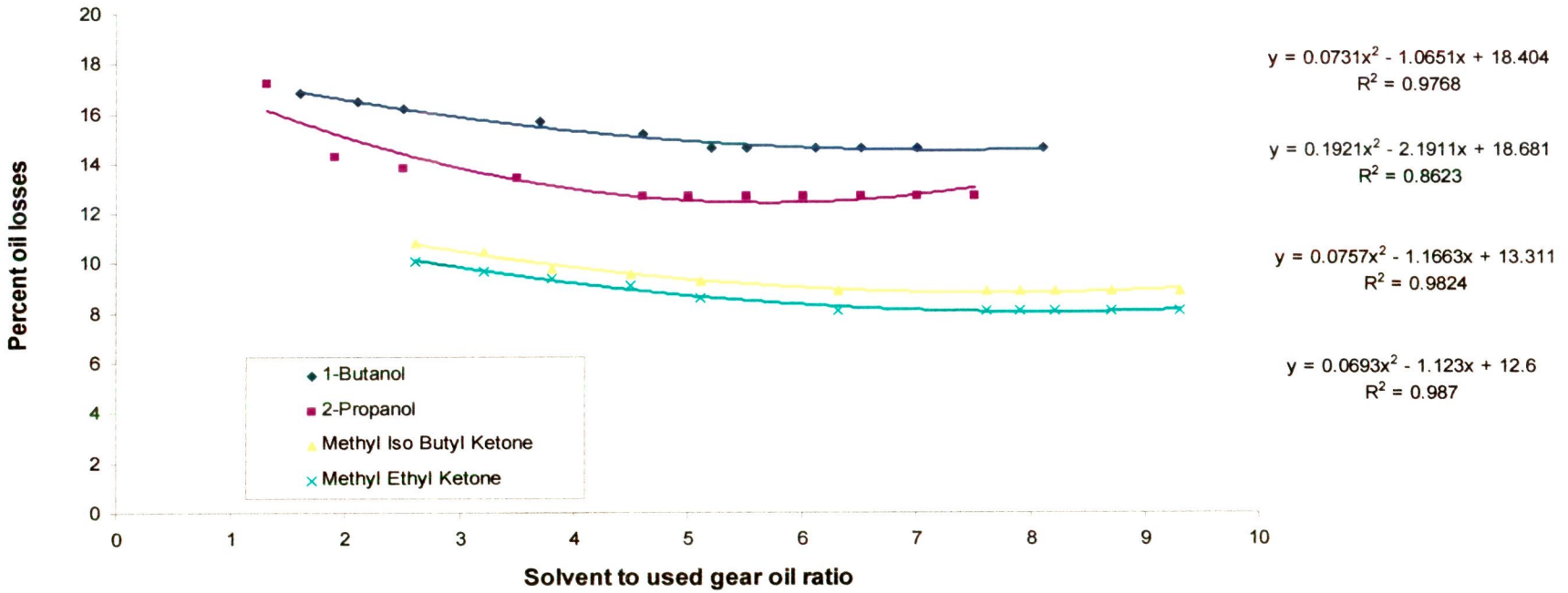
$y = 0.0978x^2 - 1.1317x + 18.451$
$R^2 = 0.9559$

$y = 0.1281x^2 - 1.3488x + 17.106$
$R^2 = 0.901$

$y = 0.0607x^2 - 0.9565x + 12.914$
$R^2 = 0.9676$

$y = 0.0399x^2 - 0.8012x + 12.178$
$R^2 = 0.9398$

Fig.4.6 Percent oil losses in extraction by various solvents at 30°C



In Fig. 4.7 the percent oil losses in this study with four solvents at 40^0C are illustrated. As seen in the figure, the two solvents (1-butanol, 2-propanol) gave almost similar percent oil losses as solvent to oil ratio increases. In figure 4.7, MIBK and MEK also gave almost similar percent oil losses as solvent to oil ratio increases. However, as solvent to oil ratio increases, the difference slightly increases. These data are well correlated by the equations given there. The experimental data deviate from the normal trend within with ±15.39% deviation which is acceptable limit.

In Fig. 4.8 the percent oil losses in this study with four solvents at 48^0C are illustrated. As seen in the figure, the two solvents (1-butanol, 2-propanol) gave almost similar percent oil losses as solvent to oil ratio increases. In figure 4.8, MIBK and MEK also gave almost similar percent oil losses as solvent to oil ratio increases. However, as solvent to oil ratio increases, the difference slightly increases. These data are well correlated by the equations given there. The experimental data deviate from the normal trend within with ±7.51% deviation which is acceptable limit.

In Fig. 4.9 the percent oil losses in this study with four solvents at 50^0C are illustrated. As seen in the figure, the two solvents (1-butanol, 2-propanol) gave almost similar percent oil losses as solvent to oil ratio increases. In figure 4.9, MIBK and MEK also gave almost similar percent oil losses as solvent to oil ratio increases. However, as solvent to oil ratio increases, the difference slightly increases. These data are well correlated by the equations given there. The experimental data deviate from the normal trend within with ±23.63% deviation which is acceptable limit.

Fig.4.7 Percent oil losses in extraction by various solvents at 40°C

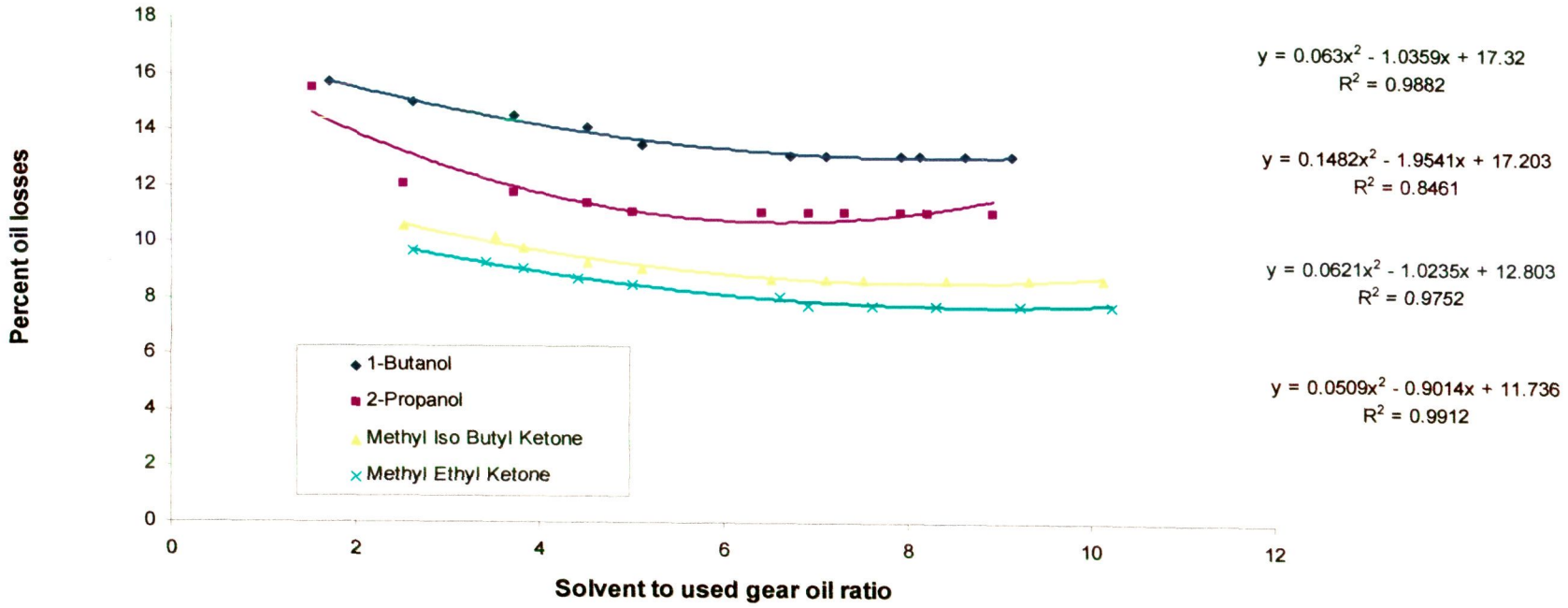


Fig.4.8 Percent oil losses in extraction by various solvents at 48°C

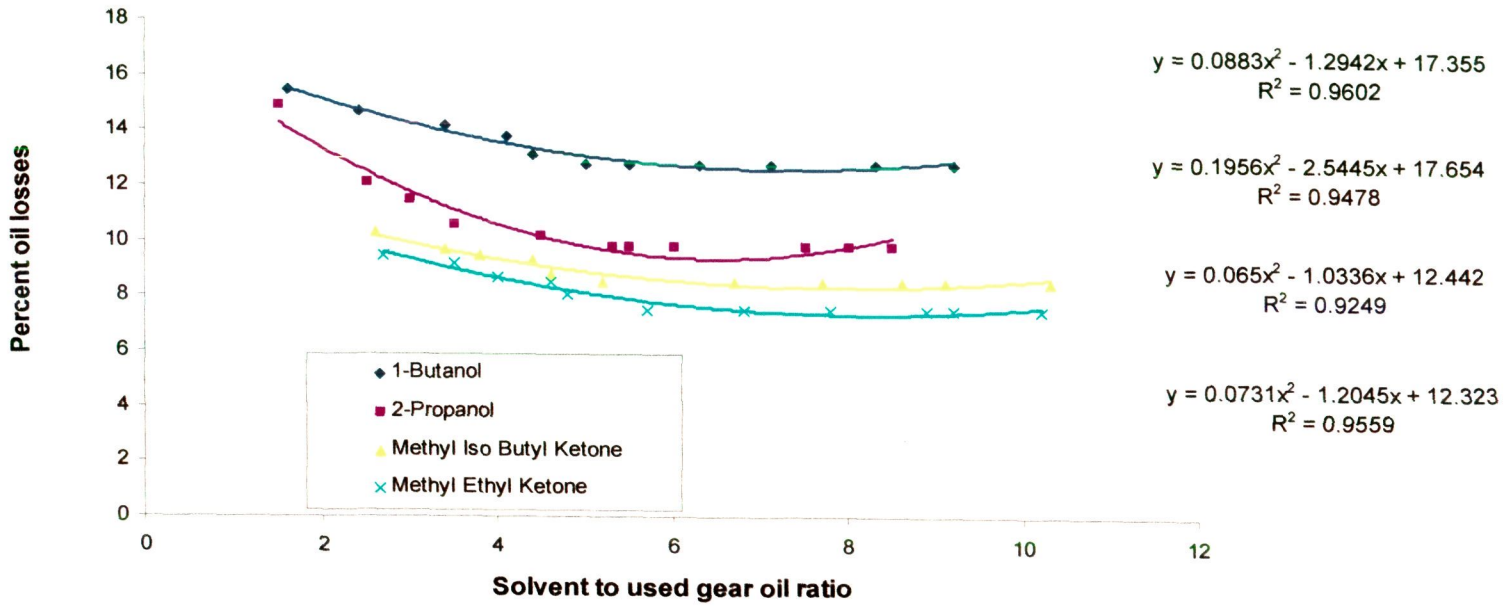
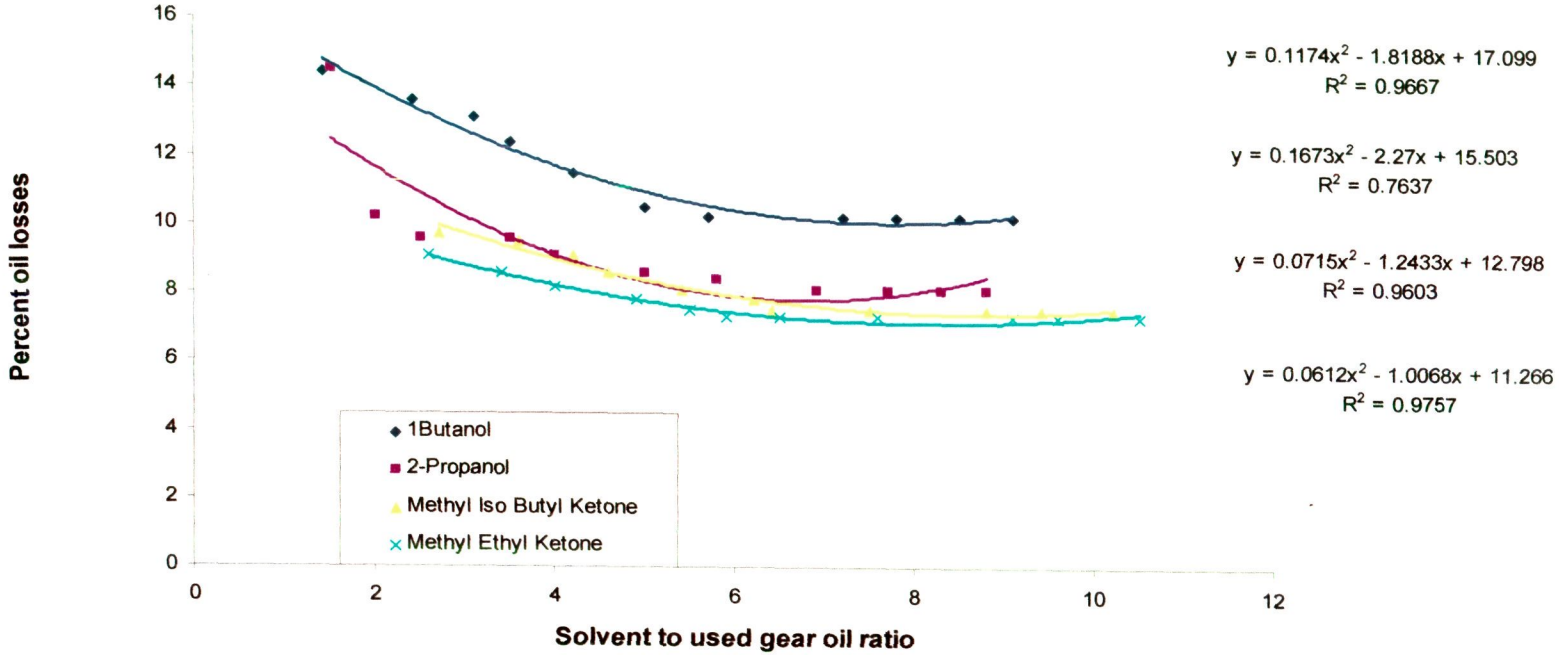


Fig.4.9 Percent oil losses in extraction by various solvents at 50°C



In Fig. 4.10 the percent oil losses in this study with four solvents at 52^0C are illustrated. As seen in the figure, the two solvents (1-butanol, 2-propanol) gave almost similar percent oil losses as solvent to oil ratio increases. In figure 4.10, MIBK and MEK also gave almost similar percent oil losses as solvent to oil ratio increases. However, as solvent to oil ratio increases, the difference slightly increases. These data are well correlated by the equations given there. The experimental data deviate from the normal trend within with ±1.88% deviation which is acceptable limit.

Fig. 4.11 shows the effect of various temperatures on the percent sludge removal for 1-butanol. The percent sludge removal decreases from 7.4 to 1.6 % with decreasing in temperature of the extraction process. In order to increase performance of the process, the percent sludge removal (P.S.R.) needs to be increased and at the same time reducing percent oil losses (P.O.L.). However, varying the temperature will not help much in improving the performance as the effect on both (P.S.R. and P.O.L.) is similar. These data are well correlated by the equations given there. The experimental data deviate from the normal trend within with ±2.42% deviation which is acceptable limit.

Fig. 4.12 shows the effect of various temperatures on the percent sludge removal for 1-propanol. The percent sludge removal decreases from 7.1 to 1.5% with decreasing in temperature of the extraction process. In order to increase performance of the process, the percent sludge removal (P.S.R.) needs to be increased and at the same time reducing percent oil losses (P.O.L.). However, varying the temperature will not help much in improving the performance as the effect on both (P.S.R. and P.O.L.) is similar. These data are

well correlated by the equations given there. The experimental data deviate from the normal trend within with ±2.81% deviation which is acceptable limit.

Fig. 4.13 shows the effect of various temperatures on the percent sludge removal for Methyl ethyl ketone. The percent sludge removal decreases from 6.5 to 1.4% with decreasing in temperature of the extraction process. In order to increase performance of the process, the percent sludge removal (P.S.R.) needs to be increased and at the same time reducing percent oil losses (P.O.L.). However, varying the temperature will not help much in improving the performance as the effect on both (P.S.R. and P.O.L.) is similar. These data are well correlated by the equations given there. The experimental data deviate from the normal trend within with ±2.46% deviation which is acceptable limit.

Fig. 4.14 shows the effect of various temperatures on the percent sludge removal for Methyl iso butyl ketone. The percent sludge removal decreases from 6.2 to 1.2% with decreasing in temperature of the extraction process. In order to increase performance of the process, the percent sludge removal (P.S.R.) needs to be increased and at the same time reducing percent oil losses (P.O.L.). However, varying the temperature will not help much in improving the performance as the effect on both (P.S.R. and P.O.L.) is similar. These data are well correlated by the equations given there. The experimental data deviate from the normal trend within with ±2.76% deviation which is acceptable limit.

Fig. 4.10 Percent oil losses in extraction by various solvents at 52°C

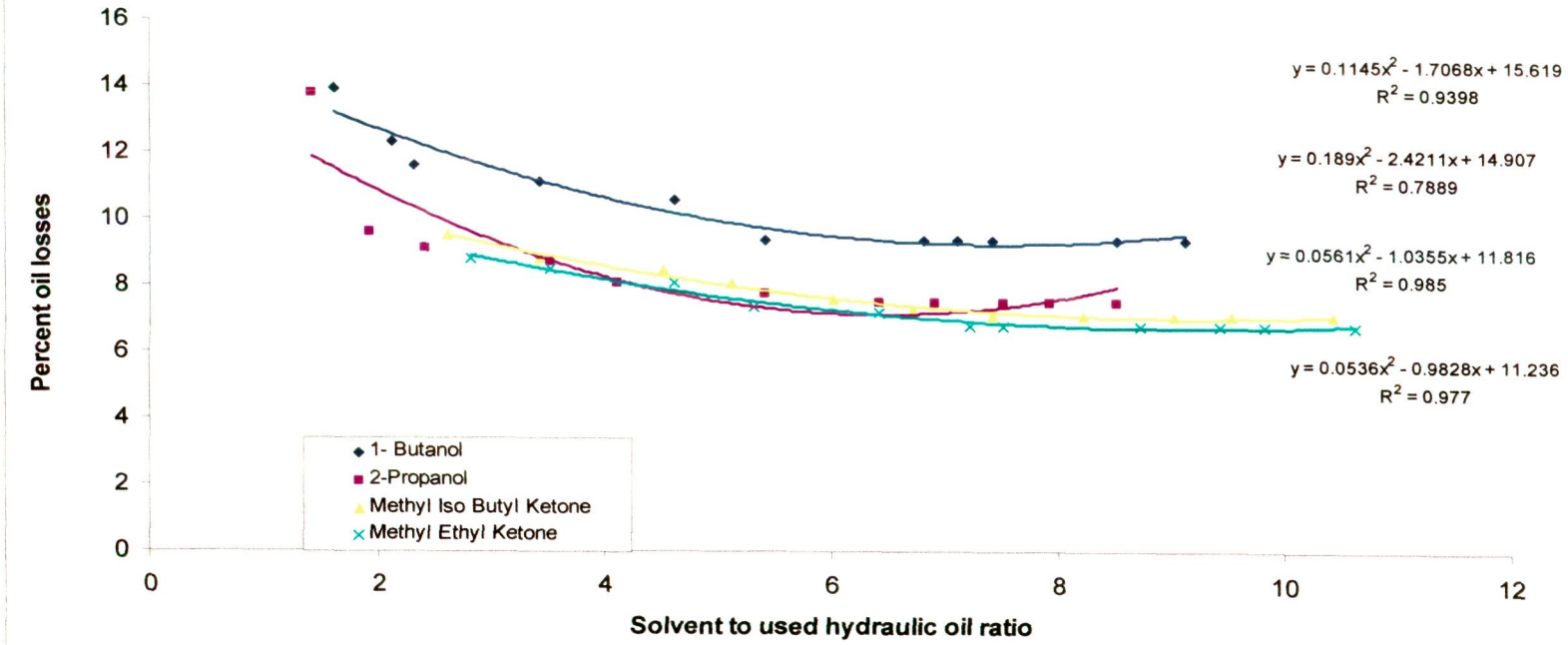
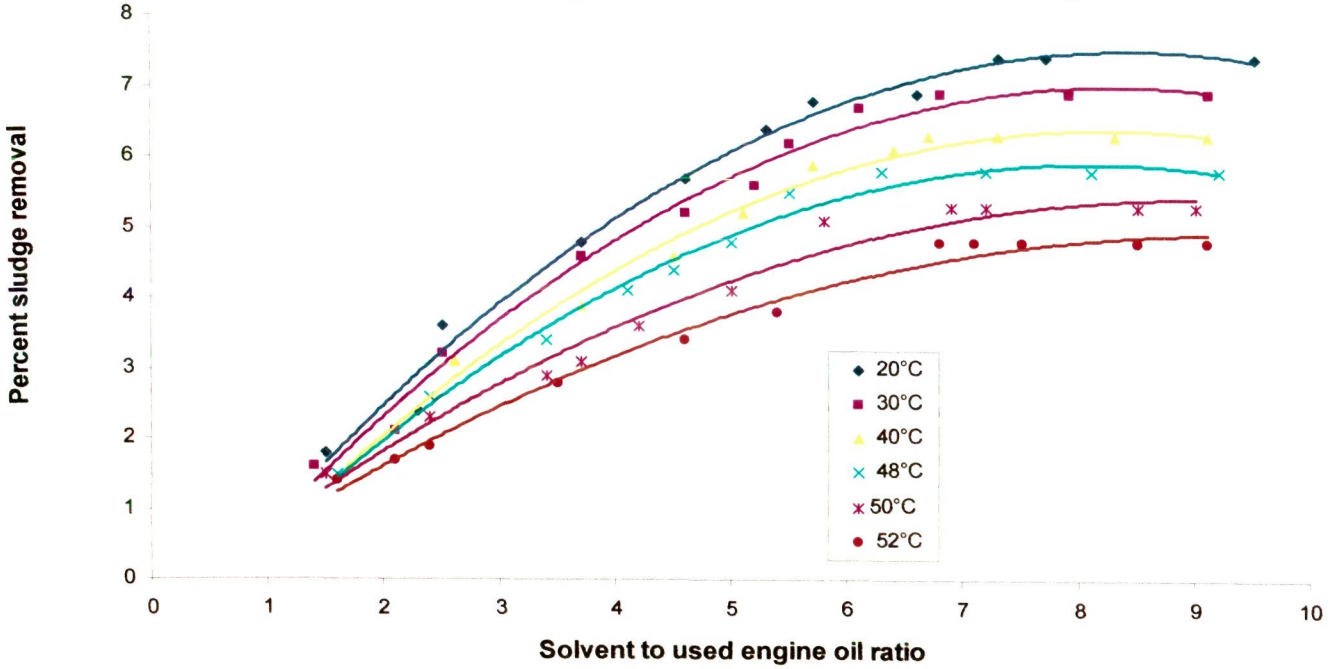


Fig.4.11 The effect of solvent to oil ratio on the extraction performance (sludge removal capability) of 1-butanol at various temperatures



$y = -0.1223x^2 + 2.0577x - 1.1448$
$R^2 = 0.9875$

$y = -0.1178x^2 + 1.9582x - 1.1197$
$R^2 = 0.9885$

$y = -0.1117x^2 + 1.8401x - 1.1757$
$R^2 = 0.9897$

$y = -0.1054x^2 + 1.71x - 1.0166$
$R^2 = 0.9885$

$y = -0.0732x^2 + 1.3192x - 0.5148$
$R^2 = 0.9758$

$y = -0.0618x^2 + 1.1514x - 0.4335$
$R^2 = 0.9888$

Fig.4.12 The effect of solvent to oil ratio on the extraction performance (sludge removal capability) of 2- propanol at various temperatures

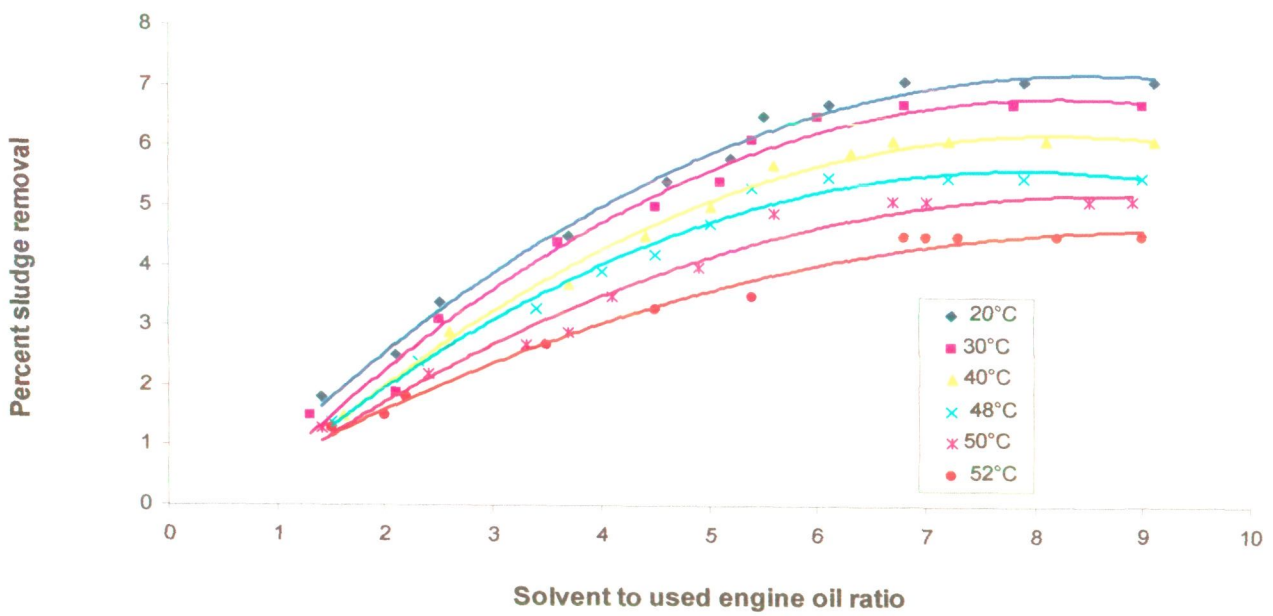
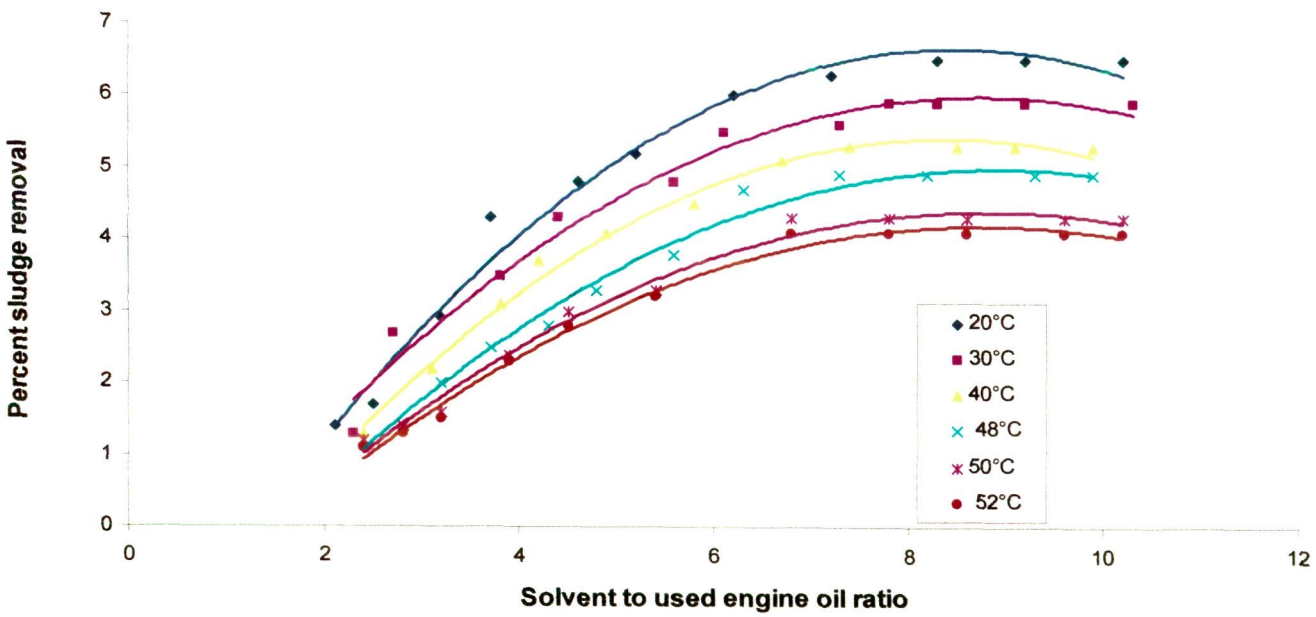


Fig.4.13 The effect of solvent to oil ratio on the extraction performance (sludge removal capability) of Methyl ethyl ketone at various temperatures



$y = -0.1288x^2 + 2.1908x - 2.6472$
$R^2 = 0.9838$

$y = -0.102x^2 + 1.7844x - 1.801$
$R^2 = 0.9754$

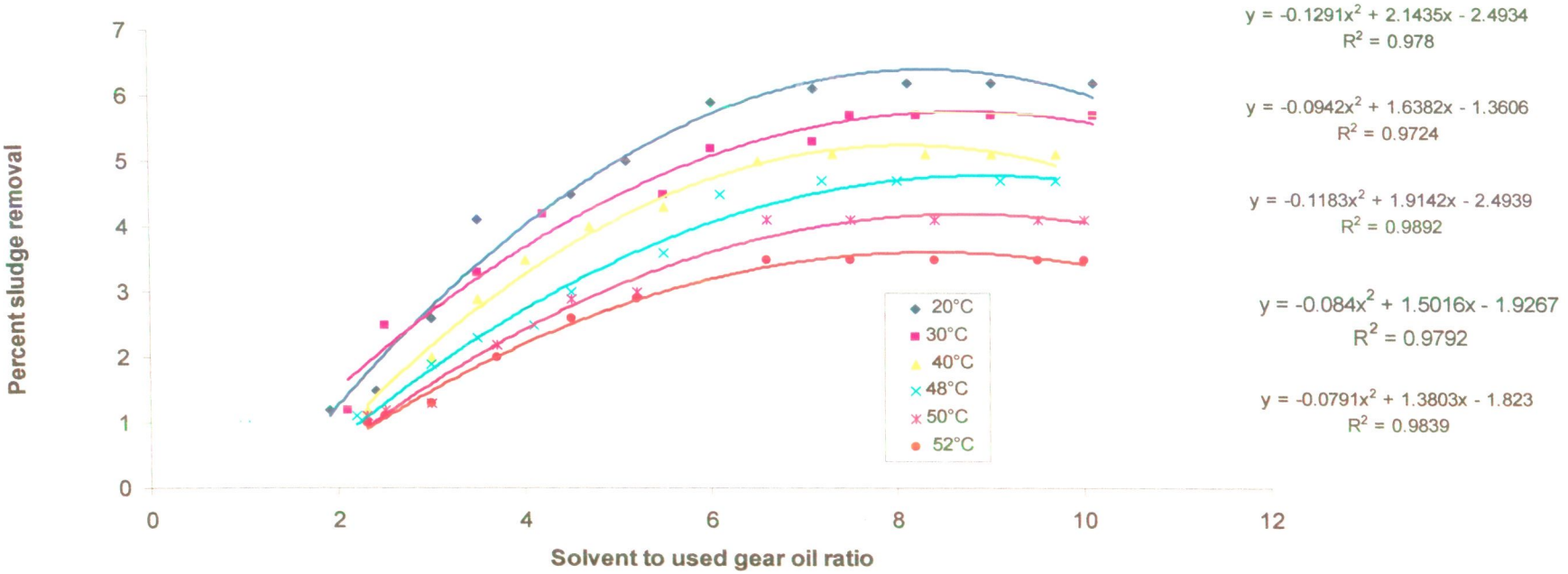
$y = -0.1114x^2 + 1.8739x - 2.4617$
$R^2 = 0.9925$

$y = -0.0914x^2 + 1.6343x - 2.313$
$R^2 = 0.9857$

$y = -0.0818x^2 + 1.4427x - 1.9619$
$R^2 = 0.9888$

$y = -0.0801x^2 + 1.4064x - 1.9735$
$R^2 = 0.9907$

Fig.4.14 The effect of solvent to oil ratio on the extraction performance (sludge removal capability) of Methyl iso butyl ketone at various temperatures



In Fig.4.15, it is observed that 1- butanol and 2- propanol produce clear solution with a sludge layer settling at the bottom of the glass tube, at lower solvent to oil ratios than MEK and MIBK. The results presented in the figure 4.15 clearly show that 1- butanol produces the highest percent sludge removal followed by 2-propanol, MIBK and MEK. On the other hand, the results obtained for P.O.L. curve demonstrate that MEK produces the lowest oil losses followed by 2-propanol, 1-butanol and MIBK irrespective of temperatures studied during this process. The experimental data are very well correlated with R^2 values in the range of 0.9866 to 0.9945. This limit is quite acceptable.

In Fig.4.16, it is observed that 1- butanol and 2- propanol produce clear solution with a sludge layer settling at the bottom of the glass tube, at lower solvent to oil ratios than MEK and MIBK. The results presented in the figure 4.16 clearly show that 1- butanol produces the highest percent sludge removal followed by 2-propanol, MIBK and MEK. On the other hand, the results obtained for P.O.L. curve demonstrate that MEK produces the lowest oil losses followed by 2-propanol, 1-butanol and MIBK irrespective of temperatures studied during this process. The experimental data are very well correlated with R^2 values in the range of 0.9812 to 0.9908. This limit is quite acceptable.

Fig.4.15 The Percent sludge removal capabilities of solvents at 20°C

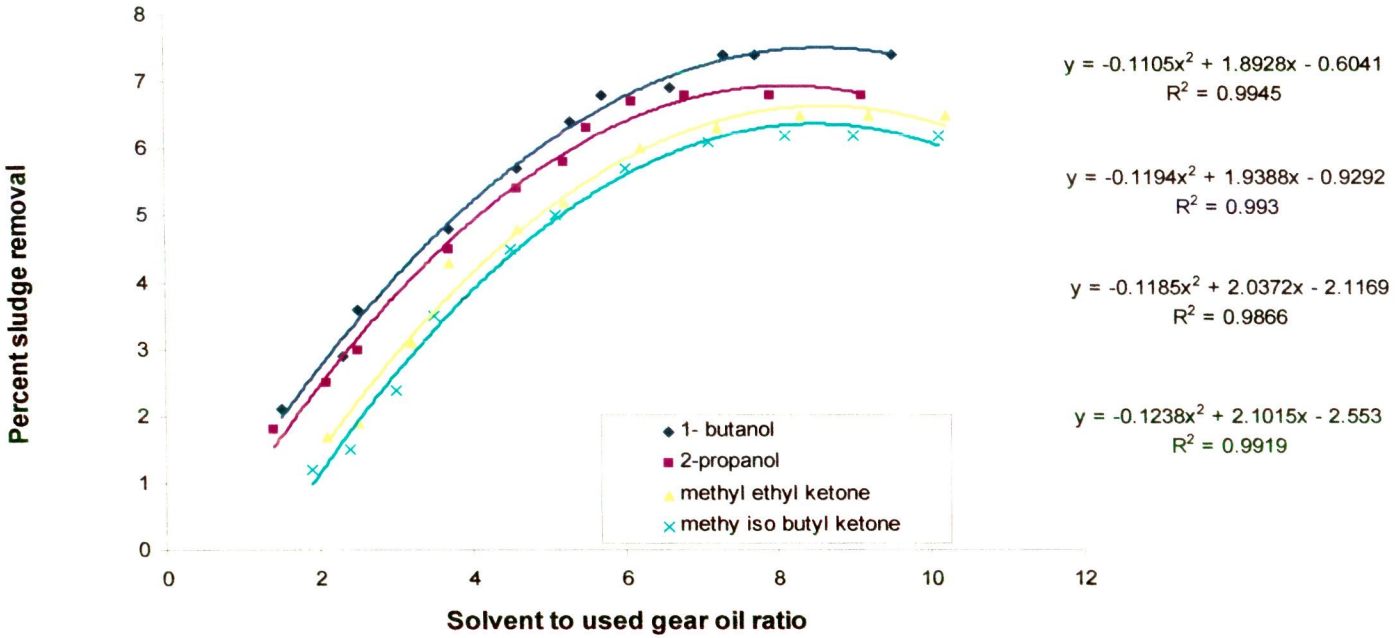
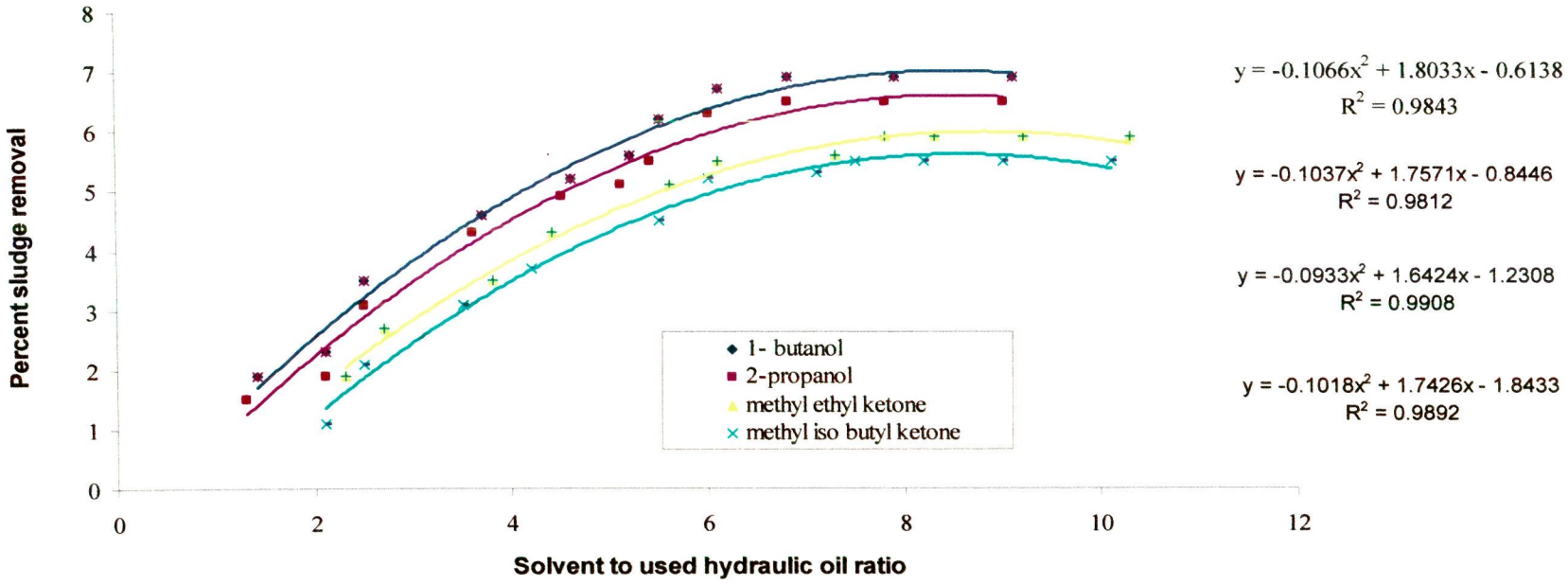


Fig.4.16 The Percent sludge removal capabilities of solvents at 30°C



In Fig.4.17, it is observed that 1- butanol and 2- propanol produce clear solution with a sludge layer settling at the bottom of the glass tube, at lower solvent to oil ratios than MEK and MIBK. The results presented in the figure 4.17 clearly show that 1- butanol produces the highest percent sludge removal followed by 2-propanol, MIBK and MEK. On the other hand, the results obtained for P.O.L. curve demonstrate that MEK produces the lowest oil losses followed by 2-propanol, 1-butanol and MIBK irrespective of temperatures studied during this process. The experimental data are very well correlated with R^2 values in the range of 0.9884 to 0.9966. This limit is quite acceptable.

In Fig.4.18, it is observed that 1- butanol and 2- propanol produce clear solution with a sludge layer settling at the bottom of the glass tube, at lower solvent to oil ratios than MEK and MIBK. The results presented in the figure 4.18 clearly show that 1- butanol produces the highest percent sludge removal followed by 2-propanol, MIBK and MEK. On the other hand, the results obtained for P.O.L. curve demonstrate that MEK produces the lowest oil losses followed by 2-propanol, 1-butanol and MIBK irrespective of temperatures studied during this process. The experimental data are very well correlated with R^2 values in the range of 0.9781 to 0.9851. This limit is quite acceptable.

In Fig.4.19, it is observed that 1- butanol and 2- propanol produce clear solution with a sludge layer settling at the bottom of the glass tube, at lower solvent to oil ratios than MEK and MIBK. The results presented in the figure 4.19 clearly show that 1- butanol produces the highest percent sludge removal followed by 2-propanol, MIBK and MEK. On the other hand, the results obtained for P.O.L. curve demonstrate that MEK produces the lowest oil losses followed by 2-

propanol, 1-butanol and MIBK irrespective of temperatures studied during this process. The experimental data are very well correlated with R^2 values in the range of 0.9718 to 0.9887. This limit is quite acceptable.

In Fig.4.20, it is observed that 1- butanol and 2- propanol produce clear solution with a sludge layer settling at the bottom of the glass tube, at lower solvent to oil ratios than MEK and MIBK. The results presented in the figure 4.20 clearly show that 1- butanol produces the highest percent sludge removal followed by 2-propanol, MIBK and MEK. On the other hand, the results obtained for P.O.L. curve demonstrate that MEK produces the lowest oil losses followed by 2-propanol, 1-butanol and MIBK irrespective of temperatures studied during this process. The experimental data are very well correlated with R^2 values in the range of 0.9868 to 0.9926. This limit is quite acceptable. Experimental data of Fig. 4.10 to Fig. 4.20 (55% data) are with a max. deviation of ±3 % only. The 20% experimental data (Fig. 4.1, 4.3, 4.5 & 4.8) deviate with a max. value of ±10%. The remaining 25% experimental data have exhibited deviation between ±15.39 to ±23.63%. Hence, it can be inferred that overall agreement is very good as far as their representation through graphs, is concerned.

Fig.4.17 The Percent sludge removal capabilities of solvents at 40°C

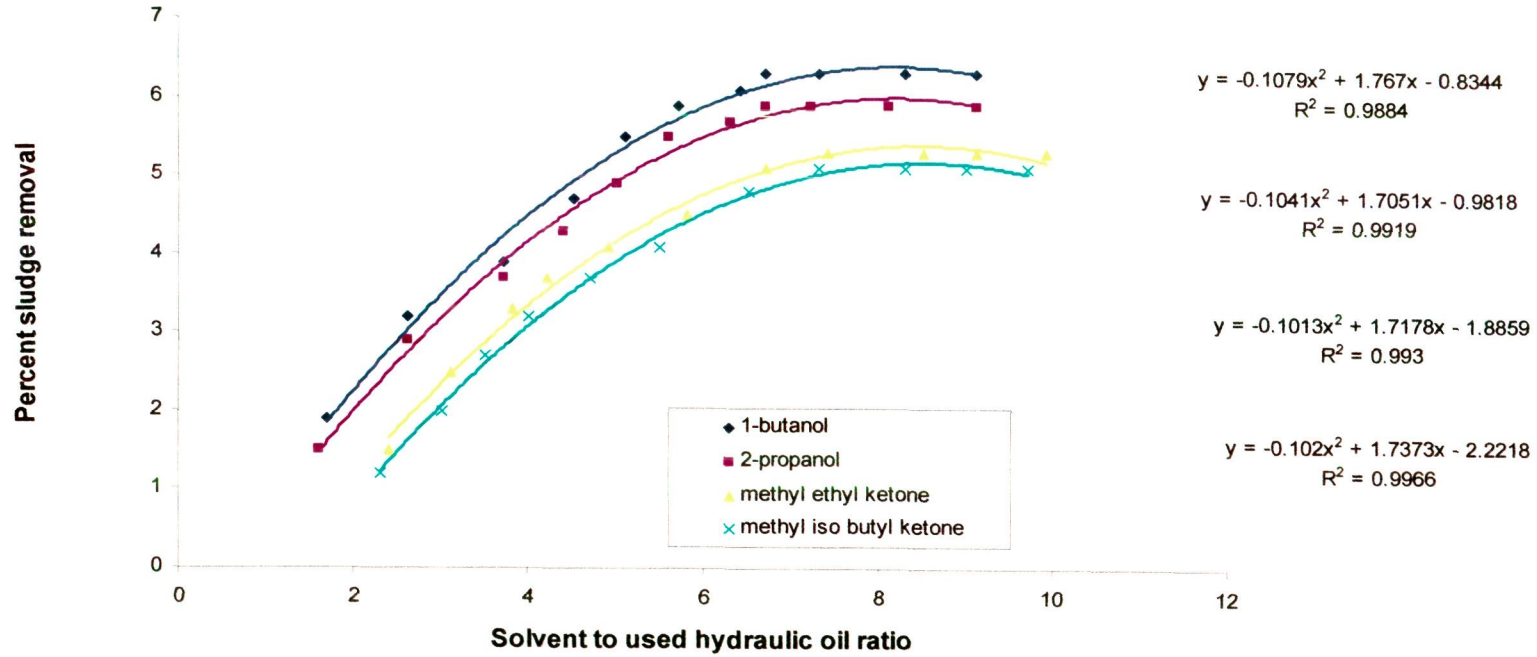


Fig.4.18 The Percent sludge removal capabilities of solvents at 48°C

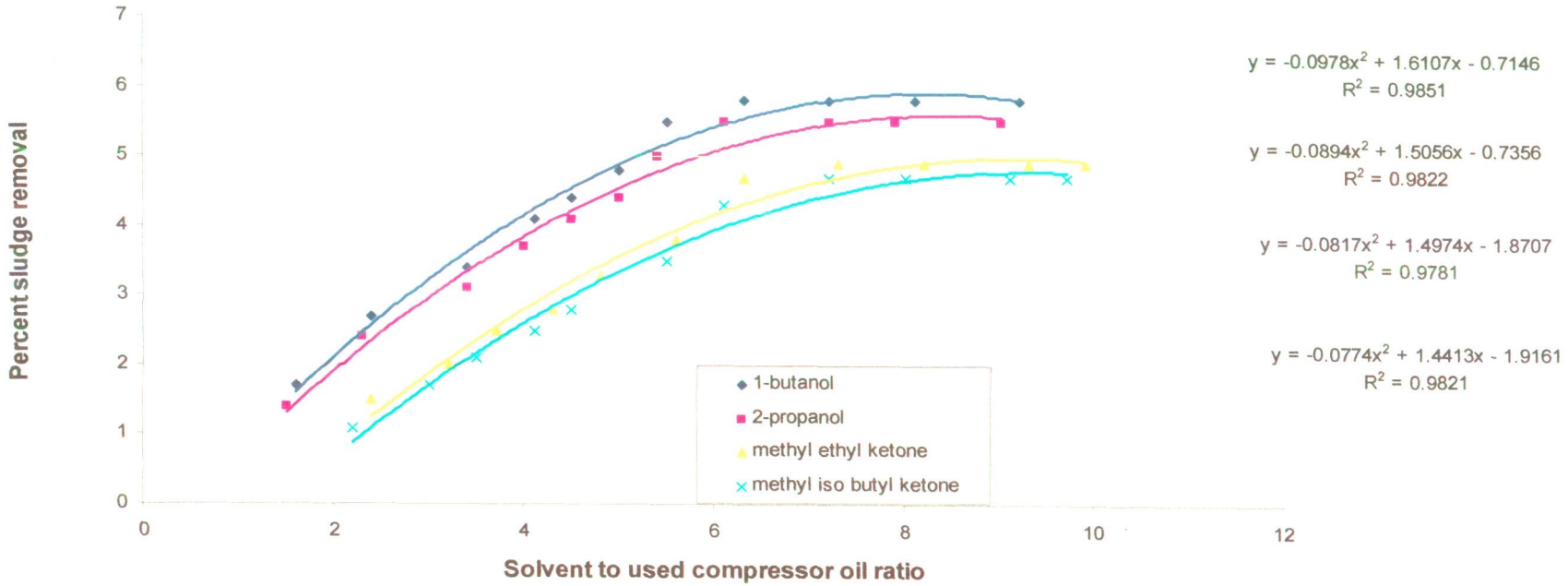


Fig.4.19 The Percent sludge removal capabilities of solvents at 50°C

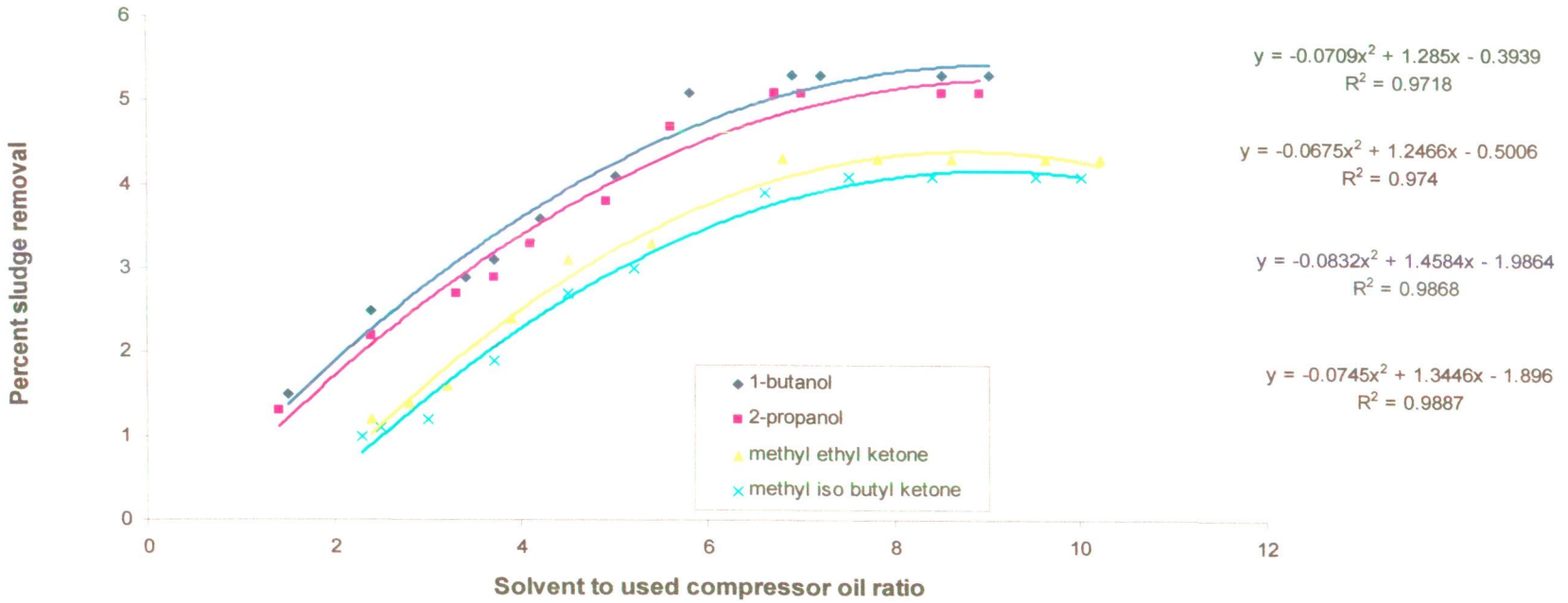
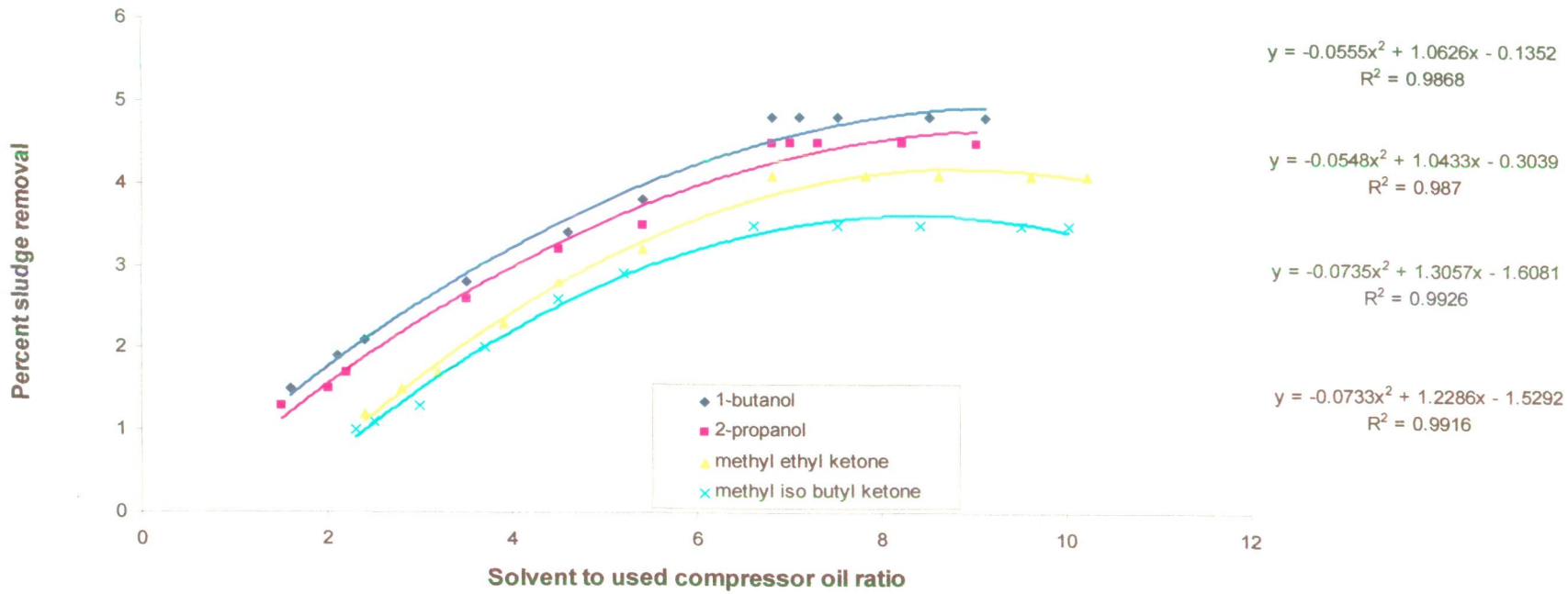


Fig.4.20 The Percent sludge removal capabilities of solvents at 52°C



4.4 CLAY TREATMENT OF SOLVENT TREATED OILS

The samples of all used lubricating oils were offered clay treatment in order to get better results. They are discussed below.

4.4.1 Engine Oils

The used engine oils treated with 50 % 1-butanol were further treated with 10.0 % clay, and the used engine oils treated with 60 % 1-butanol were subjected to clay treatment with 8.0 % as well as 10.0 % (w/v) of fuller's earth. The above quantity of clay was chosen for the reasons that below 10.0 % of clay, 50 % solvent treated oils were not showing desired improvement in colour values and 60 % 1-butanol treated oils were not showing improvement in colour and also the yield was getting decreased. Therefore, it was not economical to use clay above 10.0 %.

Tables 4.2 to 4.11 show the effect of clay treatment, centrifugal speed, colour, viscosity, flash point, pour point and ash content of the samples of refined oils. The improvement in colour is due to the higher efficiency of bleaching of fuller's earth. Decrease in ash content particles shows the proper refining as the additives and carbon particles present in used oils are removed in refining process and all the samples of base stocks prepared from different used engine oils passed the corrosion copper strip test. The saponification value was failing with in the stipulated limit for base stock.

Table 4.2 Characteristics of Base Stocks Prepared From E_1

Property/test	E_1 Refined with 50 % 1-butanol and 10 % Clay Centrifuge speed			E_1 Refined with 60 % 1-butanol and 8 % Clay Centrifuge speed			E_1 Refined with 60 % 1-butanol and 10 % Clay Centrifuge speed		
	500 r.p.m.	1000 r.p.m.	1500 r.p.m.	500 r.p.m.	1000 r.p.m.	1500 r.p.m.	500 r.p.m.	1000 r.p.m.	1500 r.p.m.
1. Colour	+5.5	+4.0	+3.0	+8.5	+5.5	+4.5	+5.0	+3.5	+2.5
2. Viscosity (cst) at 40°C	39.0	46.0	56.0	40.0	47.0	56.5	40.0	47.5	57.0
3. Flash Point (°C)	144	176	204	144	176	204	146	176	204
4. Pour Point (°C)	-18	- 18	-18	- 18	-18	-18	-18	- 18	-18
5. Ash Content (%)	0.007	0.007	0.006	0.007	0.007	0.007	0.006	0.006	0.006
6. Acidity (mg KOH/g of oil) a. Inorganic b. Organic	 Nil 0.041	 Nil 0.038	 Nil 0.039	 Nil 0.043	 Nil 0.043	 Nil 0.042	 Nil 0.040	 Nil 0.039	 Nil 0.039
7. Saponification Value(mg KOH/g of oil)	0.6	0.6	0.5	0.6	0.6	0.5	0.5	0.5	0.6
8. Corrosion, Copper Strip 3h at 100°C	1b	1b	1b	1b	1b	1b	1b	1b	1b
9. Yield of Refined Oil (%)	58.0	52.0	44.0	58.5	53.0	45.8	59.0	51.5	45.0

Table 4.3 Characteristics of Base Stocks Prepared From E_2

Property/test	E_2 Refined with 50 % 1-butanol and 10% Clay Centrifuge speed			E_2 Refined with 60 % 1-butanol and 8 % Clay Centrifuge speed			E_2 Refined with 60 % 1-butanol and 10 % Clay Centrifuge speed		
	500 r.p.m.	1000 r.p.m.	1500 r.p.m.	500 r.p.m.	1000 r.p.m.	1500 r.p.m.	500 r.p.m.	1000 r.p.m.	1500 r.p.m.
1. Colour	+5.5	+4.0	+2.5	+7.5	+5.0	+3.5	+5.0	+3.5	+2.5
2. Viscosity (cst) at 40°C	45.0	57.0	69.0	45.5	57.5	69.5	45.5	57.5	70.0
3. Flash Point (°C)	140	176	210	140	176	210	140	176	210
4. Pour Point (°C)	-7	-7	-7	-7	-7	-7	-7	-7	-7
5. Ash Content (%)	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007
6. Acidity (mg KOH/g of oil) a. Inorganic b. Organic	 Nil 0.043	 Nil 0.043	 Nil 0.041	 Nil 0.045	 Nil 0.045	 Nil 0.045	 Nil 0.042	 Nil 0.042	 Nil 0.041
7. Saponification Value (mg KOH/g of oil)	0.7	0.7	0.6	0.8	0.8	0.7	0.7	0.7	0.6
8. Corrosion, Copper Strip 3h at 100°C	1b	1b	1b	1b	1b	1b	1b	1b	1b
9. Yield of Refined Oil (%)	61.0	54.0	47.0	62.0	52.0	47.5	61.0	54.5	47.0

Table 4.4 Characteristics of Base Stocks Prepared From E_3

Property/test	E_3 Refined with 50% 1-butanol and 10 % Clay Centrifuge speed			E_3 Refined with 60% 1-butanol and 8 % Clay Centrifuge speed			E_3 Refined with 60% 1-butanol and 10 % Clay Centrifuge speed		
	500 r.p.m.	1000 r.p.m.	1500 r.p.m.	500 r.p.m.	1000 r.p.m.	1500 r.p.m.	500 r.p.m.	1000 r.p.m.	1500 r.p.m.
1. Colour	+5.0	+4.5	+3.5	+6.5	+5.5	+4.0	+4.0	+3.5	+2.0
2. Viscosity (cst) at 40°C	47.5	57.5	63.5	48.0	57.5	63.5	48.5	58.0	64.0
3. Flash Point (°C)	143	180	205	145	181	205	143	181	205
4. Pour Point (°C)	-9	-9	-9	-9	-9	-9	-9	-9	-9
5. Ash Content (%)	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007
6. Acidity (mg KOH/g of oil) a. Inorganic b. Organic	 Nil 0.038	 Nil 0.038	 Nil 0.037	 Nil 0.040	 Nil 0.040	 Nil 0.037	 Nil 0.036	 Nil 0.036	 Nil 0.034
7. Saponification Value (mg KOH/g of oil)	0.5	0.5	0.5	0.4	0.5	0.4	0.4	0.4	0.4
8. Corrosion, Copper Strip 3h at 100°C	1b	1b	1b	1b	1b	1b	1b	1b	1b
9. Yield of Refined Oil (%)	64.0	59.5	52.0	63.0	58.0	51.5	66.0	60.5	52.0

Table 4.5 Characteristics of Base Stocks Prepared From E_4

Property/test	E_4 Refined with 50% 1-butanol and 10 % Clay Centrifuge speed			E_4 Refined with 60% 1-butanol and 8 % Clay Centrifuge speed			E_4 Refined with 60% 1-butanol and 10% Clay Centrifuge speed		
	500 r.p.m.	1000 r.p.m.	1500 r.p.m.	500 r.p.m.	1000 r.p.m.	1500 r.p.m.	500 r.p.m.	1000 r.p.m.	1500 r.p.m.
1. Colour	+7.5	+6.0	+3.5	+8.5	+6.5	+4.0	+5.5	+3.5	+2.0
2. Viscosity (cst) at 40°C	41.5	53.5	65.0	41.5	54.0	65.0	41.5	54.0	65.5
3. Flash Point (°C)	148	184	212	148	184	212	150	183	212
4. Pour Point (°C)	-7	-7	-7	-7	-7	-7	-7	-7	-7
5. Ash Content (%)	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.006
6. Acidity (mg KOH/g of oil) a. Inorganic b. Organic	 Nil 0.030	 Nil 0.031	 Nil 0.031	 Nil 0.033	 Nil 0.033	 Nil 0.031	 Nil 0.029	 Nil 0.029	 Nil 0.029
7. Saponification Value (mg KOH/g of oil)	0.6	0.6	0.6	0.7	0.6	0.7	0.7	0.6	0.6
8. Corrosion, Copper Strip 3h at 100°C	1b	1b	1b	1b	1b	1b	1b	1b	1b
9. Yield of Refined Oil (%)	60.0	56.0	53.0	63.5	58.0	56.5	62.5	56.0	53.5

Table 4.6 Characteristics of Base Stocks Prepared From E_5

Property/test	E_5 Refined with 50 % 1-butanol and 10 % Clay Centrifuge speed			E_5 Refined with 60 % 1-butanol and 8 % Clay Centrifuge speed			E_5 Refined with 60 % 1-butanol and 10 %Clay Centrifuge speed		
	500 r.p.m.	1000 r.p.m.	1500 r.p.m.	500 r.p.m.	1000 r.p.m.	1500 r.p.m.	500 r.p.m.	1000 r.p.m.	1500 r.p.m.
1. Colour	+8.5	+4.5	+3.0	+7.0	+4.5	+3.5	+6.5	+3.5	+2.0
2. Viscosity (cst) at 40°C	49.0	56.0	68.5	49.0	56.5	69.0	49.5	57.0	69.5
3. Flash Point (°C)	150	186	215	148	187	215	150	186	215
4. Pour Point (°C)	-8	-8	-8	-8	-8	-8	-8	-8	-8
5. Ash Content (%)	0.008	0.008	0.007	0.008	0.007	0.007	0.007	0.007	0.007
6. Acidity (mg KOH/g of oil) a. Inorganic b. Organic	 Nil 0.036	 Nil 0.035	 Nil 0.035	 Nil 0.038	 Nil 0.037	 Nil 0.037	 Nil 0.034	 Nil 0.034	 Nil 0.033
7. Saponification Value (mg KOH/g of oil)	0.4	0.5	0.5	0.4	0.4	0.5	0.4	0.4	0.4
8. Corrosion, Copper Strip 3h at 100°C	1b	1b	1b	1b	1b	1b	1b	1b	1b
9. Yield of Refined Oil (%)	60.5	54.0	49.0	61.5	54.0	51.0	61.0	52.5	49.0

Table 4.7 Characteristics of Base Stocks Prepared From E_6

Property/test	E_6 Refined with 50% 1-butanol and 10 % Clay Centrifuge speed			E_6 Refined with 60% 1-butanol and 8 % Clay Centrifuge speed			E_6 Refined with 60% 1-butanol and 10 % Clay Centrifuge speed		
	500 r.p.m.	1000 r.p.m.	1500 r.p.m.	500 r.p.m.	1000 r.p.m.	1500 r.p.m.	500 r.p.m.	1000 r.p.m.	1500 r.p.m.
1. Colour	+4.5	+3.5	+3.0	+6.5	+4.5	+3.5	+3.5	+3.0	+2.0
2. Viscosity (cst) at 40°C	48.5	53.5	60.0	49.5	54.0	60.5	50.5	54.0	61.0
3. Flash Point (°C)	152	178	210	152	179	210	152	180	210
4. Pour Point (°C)	-12	-12	-12	-12	-12	-12	-12	-12	-12
5. Ash Content (%)	0.008	0.008	0.007	0.008	0.007	0.007	0.007	0.007	0.007
6. Acidity (mg KOH/g of oil) a. Inorganic b. Organic	 Nil 0.041	 Nil 0.041	 Nil 0.040	 Nil 0.043	 Nil 0.044	 Nil 0.043	 Nil 0.039	 Nil 0.039	 Nil 0.038
7. Saponification Value (mg KOH/g of oil)	0.6	0.5	0.6	0.6	0.7	0.6	0.6	0.6	0.5
8. Corrosion, Copper Strip 3h at 100°C	1b	1b	1b	1b	1b	1b	1b	1b	1b
9. Yield of Refined Oil (%)	59.0	55.0	52.0	57.5	54.0	50.0	60.5	55.5	53.0

Table 4.8 Characteristics of Base Stocks Prepared From E_7

Property/test	E_7 Refined with 50% 1-butanol and 10 % Clay Centrifuge speed			E_7 Refined with 60% 1-butanol and 8 % Clay Centrifuge speed			E_7 Refined with 60% 1-butanol and 10 % Clay Centrifuge speed		
	500 r.p.m.	1000 r.p.m.	1500 r.p.m.	500 r.p.m.	1000 r.p.m.	1500 r.p.m.	500 r.p.m.	1000 r.p.m.	1500 r.p.m.
1. Colour	+4.5	+3.5	+2.5	+5.5	+4.0	+3.0	+4.0	+3.5	+2.5
2. Viscosity (cst) at 40°C	53.5	57.0	68.0	53.5	57.5	68.5	54.0	58.0	69.0
3. Flash Poin(°C)	165	198	215	165	198	215	165	198	215
4. Pour Point(°C)	-6	-6	-6	-6	-6	-6	-6	-6	-6
5. Ash Content (%)	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.005	0.005
6. Acidity (mg KOH/g of oil) a. Inorganic b. Organic	 Nil 0.032	 Nil 0.031	 Nil 0.031	 Nil 0.034	 Nil 0.033	 Nil 0.032	 Nil 0.029	 Nil 0.028	 Nil 0.027
7. Saponification Value (mg KOH/g of oil)	0.5	0.5	0.6	0.6	0.6	0.5	0.5	0.4	0.4
8. Corrosion, Copper Strip 3h at 100°C	1b	1b	1b	1b	1b	1b	1a	1a	1a
9. Yield of Refined Oil (%)	66.0	61.0	54.0	67.0	63.0	55.0	67.0	62.0	54.0

Table 4.9 Characteristics of Base Stocks Prepared From E_8

Property/test	E_8 Refined with 50% 1-butanol and 10 % Clay Centrifuge speed			E_8 Refined with 60% 1-butanol and 8 % Clay Centrifuge speed			E_8 Refined with 60% 1-butanol and 10 % Clay Centrifuge speed		
	500 r.p.m.	1000 r.p.m.	1500 r.p.m.	500 r.p.m.	1000 r.p.m.	1500 r.p.m.	500 r.p.m.	1000 r.p.m.	1500 r.p.m.
1. Colour	+5.0	+4.5	+3.0	+6.5	+4.5	+3.5	+4.5	+3.5	+2.0
2. Viscosity (cst) at 40°C	45.5	60.0	69.5	46.0	60.5	69.5	46.0	61.0	70.0
3. Flash Point (°C)	155	180	207	156	178	207	155	181	207
4. Pour Point (°C)	-7	-7	-7	-7	-7	-7	-7	-7	-7
5. Ash Content (%)	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.005	0.005
6. Acidity (mg KOH/g of oil) a. Inorganic b. Organic	Nil 0.043	Nil 0.042	Nil 0.043	Nil 0.045	Nil 0.045	Nil 0.045	Nil 0.041	Nil 0.040	Nil 0.040
7. Saponification Value (mg KOH/g of oil)	0.5	0.5	0.5	0.7	0.7	0.7	0.5	0.5	0.6
8. Corrosion, Copper Strip 3h at 100°C	1b	1b	1b	2a	2a	2a	1b	1b	1b
9. Yield of Refined Oil (%)	62.5	59.5	57.0	66.0	61.5	59.0	65.0	61.0	58.0

Table 4.10 Characteristics of Base Stocks Prepared From E_9

Property/test	E_9 Refined with 50% 1-butanol and 10 % Clay Centrifuge speed			E_9 Refined with 60% 1-butanol and 8 % Clay Centrifuge speed			E_9 Refined with 60% 1-butanol and 10 % Clay Centrifuge speed		
	500 r.p.m.	1000 r.p.m.	1500 r.p.m.	500 r.p.m.	1000 r.p.m.	1500 r.p.m.	500 r.p.m.	1000 r.p.m.	1500 r.p.m.
1. Colour	+5.0	+4.5	+3.0	+6.0	+4.5	+3.5	+4.5	+3.0	+2.0
2. Viscosity (cst) at 40°C	58.5	74.0	87.0	59.0	74.5	87.5	59.0	75.0	88.0
3. Flash Point (°C)	190	202	215	190	202	215	190	202	215
4. Pour Point (°C)	-6	-6	-6	-6	-6	-6	-6	-6	-6
5. Ash Content (%)	0.006	0.006	0.005	0.006	0.006	0.005	0.006	0.005	0.005
6. Acidity (mg KOH/g of oil) a. Inorganic b. Organic	Nil 0.038	Nil 0.039	Nil 0.039	Nil 0.039	Nil 0.040	Nil 0.040	Nil 0.036	Nil 0.037	Nil 0.036
7. Saponification Value (mg KOH/g of oil)	0.6	0.5	0.5	0.6	0.6	0.5	0.5	0.5	0.5
8. Corrosion, Copper Strip 3h at 100°C	1b	1b	1b	1b	1b	1b	1b	1b	1b
9. Yield of Refined Oil (%)	67.0	66.0	64.0	71.0	69.0	66.0	72.0	70.0	67.0

Table 4.11 Characteristics of Base Stocks Prepared From E_{10}

Property/test	E_{10} Refined with 50% 1-butanol and 10 % Clay Centrifuge speed			E_{10} Refined with 60% 1-butanol and 8 % Clay Centrifuge speed			E_{10} Refined with 60% 1-butanol and 10 % Clay Centrifuge speed		
	500 r.p.m.	1000 r.p.m.	1500 r.p.m.	500 r.p.m.	1000 r.p.m.	1500 r.p.m.	500 r.p.m.	1000 r.p.m.	1500 r.p.m.
1. Colour	+4.5	+3.5	+2.0	+5.0	+4.5	+3.5	+3.5	+3.0	+2.0
2. Viscosity (cst) at 40°C	61.5	73.0	83.0	62.0	75.0	84.0	62.5	76.0	84.5
3. Flash Point (°C)	198	205	220	198	205	220	198	205	220
4. Pour Point (°C)	-7	-7	-7	-7	-7	-7	-7	-7	-7
5. Ash Content (%)	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005
6. Acidity (mg KOH/g of oil) a. Inorganic b. Organic	 Nil 0.037	 Nil 0.036	 Nil 0.036	 Nil 0.038	 Nil 0.038	 Nil 0.036	 Nil 0.035	 Nil 0.034	 Nil 0.035
7. Saponification Value (mg KOH/g of oil)	0.4	0.4	0.5	0.5	0.5	0.5	0.4	0.5	0.4
8. Corrosion, Copper Strip 3h at 100°C	1b	1b	1b	1b	1b	1b	1a	1a	1a
9. Yield of Refined Oil (%)	73.0	72.0	70.0	74.0	72.5	70.5	75.0	73.5	71.5

Table 4.2 shows the improvement in colour of the refined oils (solvent-clay treated) from [+ 5.5 to + 3.0], [+ 8.5 to + 4.5] and [+ 5.0 to + 2.5] ASTM units on treatment with 50 % 1-butanol and 10 % clay [50S 10C], 60 % 1-butanol and 8 % clay [60S 8C] and 60 % 1-butanol and 10 % clay [60S 10C] at 250°C, 280°C and 300°C respectively. The percent reduction in colour at 300°C over that at 250°C was 45.5 , 47.0 and 50.0 for refined engine oils under the conditions of [50S 10C], [60S 8C] and [60S 8C], respectively. The used lubricating oils samples are centrifuge up to 500 r.p.m. to 1500 r.p.m. The colour of refined engine oil under [60S 8C] condition at 250°C was poor, hence it was discarded. The difference in colour and yield of refined engine oils in [50S 10C] and [60S 10C] condition at 300°C was [+0.5] ASTM and 1 %, respectively. Therefore, both the treatments are observed to be suitable for satisfactory and economic refining of used engine oil E_1. The viscosity and flash point of refined oils were in the range of 39.0 to 57.0 cst at 40°C and from 144°C to 204°C, respectively. The increase in viscosity and flash point was observed at 300°C which is due to higher removal of lower fractions at this temperature. The pour point under the best conditions of refining of E_1 was observed to be -18°C. The ash content of the refined oils was insignificant indicating better processing. Total (organic) acidity was in the range of 0.038 to 0.043 mg KOH/g of oil whereas the inorganic acidity was nil.

Table 4.3 shows the improvement in colour of the refined oils from [+ 5.5 to + 2.5], [+ 7.5 to + 3.5] and [+ 5.0 to + 2.5] ASTM units on treatment with [50S 10C], [60S 8C] and [60S 10C] at 250°C, 280°C and 300°C, respectively. The percent reduction in colour at 300°C over that at 250°C was 54.5, 53.0 and 50.0 for refined engine oils under the conditions of [50S 10C], [60S 8C] and

[60S 10C], respectively. The used lubricating oils samples are centrifuge up to 500 r.p.m. to 1500 r.p.m. The refined oils having colour above + 4.5 ASTM units were discarded. There was no difference in colour and yield of the refined oils in [50S 10C], [60S 8C] condition at 300°C, therefore, both the treatment can be applied for satisfactory and economical refining of used engine oil E_2. The viscosity and flash point of refined oils were in the range of 45.0 to 70.0 cst at 40°C and from 140°C to 210°C, respectively. The ash content of the refined oils was insignificant. The pour point under the best conditions of refining of E_2 was observed to be -7°C. Total (organic) acidity was in the range of 0.041 to 0.045 mg KOH/g of oil whereas the inorganic acidity was nil.

Table 4.4 shows the improvement in colour of the refined oils from [+ 5.5 to +3.5], [+6.5 to +4.0] and [+4.0 to + 2.0] ASTM units on treatment with [50S 10C], [60S 8C] and [60S 10C] at 250°C, 280°C and 300°C, respectively. The percent reduction in colour at 300°C over that at 250°C was 30, 38 and 50.0 for refined oils under the conditions of [50S 10C], [60S 8C] and [60S 10C], respectively. The used lubricating oils samples are centrifuge up to 500 r.p.m. to 1500 r.p.m. The colour and yield of the refined oils in [60S 10C] condition at 300°C, were better in comparison to refined oils prepared under other two set of conditions, therefore, this treatment can be applied for satisfactory and economical refining of used engine oil E_3. The viscosity and flash point of refined oils were in the range of 47.5 to 64.0 cst at 40°C and from 143°C to 205°C, respectively. The ash content of the refined oils was insignificant. The pour point under the best conditions of refining of E_3 was observed to be -9°C. Total (organic) acidity was in the range of 0.034 to 0.040 mg KOH/g of oil whereas the inorganic acidity was nil.

Table 4.5 shows the improvement in colour of the refined oils from [+7.5 to +3.5], [+8.5 to +4.0] and [+5.5 to + 2.0] ASTM units on treatment with [50S 10C], [60S 8C] and [60S 10C] at 250°C, 280°C and 300°C, respectively. The percent reduction in colour at 300°C over that at 250°C was 53, 58 and 64 for refined oils under the conditions of [50S 10C], [60S 8C] and [60S 10C], respectively. The used lubricating oils samples are centrifuge up to 500 r.p.m. to 1500 r.p.m. The colour and yield of the refined oils in [60S 10C] condition at 300°C, were better in comparison to refined oils prepared under other conditions, therefore, this treatment can be applied for satisfactory and economical refining of used engine oil E_4. The viscosity and flash point of refined oils were in the range of 41.5 to 65.5 cst at 40°C and from 148°C to 212°C, respectively. The ash content of the refined oils was insignificant. The pour point under the best conditions of refining of E_4 was observed to be -7°C. Total (organic) acidity was in the range of 0.029 to 0.033 mg KOH/g of oil whereas the inorganic acidity was nil.

Table 4.6 shows the improvement in colour of the refined oils from [+8.5 to +3.0], [+7.0 to +3.5] and [+6.5 to + 2.0] ASTM units on treatment with [50S 10C], [60S 8C] and [60S 10C] at 250°C, 280°C and 300°C, respectively. The used lubricating oils samples are centrifuge up to 500 r.p.m. to 1500 r.p.m. The percent reduction in colour at 300°C over that at 250°C was 65, 50, and 69 for refined oils under the conditions of [50S 10C], [60S 8C] and [60S 10C], respectively. Although, the yield was slightly lower for [60S 10C], refined oils in comparison to [60S 8C] refined oils but the colour was better for [60S 10C] refined oils, therefore, [60S 10C] treatment can be applied for satisfactory refining of used engine oil E_5. The viscosity and flash point of refined oils were in the range of 49.0 to 69.5 cst at 40° C and from 148°C to 215°C, respectively.

The ash content of the refined oils was insignificant. The pour point under the best conditions of refining of E_5 was observed to be -8°C. Total (organic) acidity was in the range of 0.033 to 0.038 mg KOH/g of oil whereas the inorganic acidity was nil.

Table 4.7 shows the improvement in colour of the refined oils from [+4.5 to +3.0], [+6.5 to +3.5] and [+3.5 to + 2.0] ASTM units on treatment with [50S 10C], [60S 8C] and [60S 10C] at 250°C, 280°C and 300°C, respectively. The used lubricating oils samples are centrifuge up to 500 r.p.m. to 1500 r.p.m. The percent reduction in colour at 300°C over that at 250°C was 33, 46 and 43 for refined oils under the conditions of [50S 10C], [60S 8C] and [60S 10C], respectively. The colour and yield were good for [50S 10C] and [60S 10C] refined oils, therefore, both the treatment can be applied for satisfactory and economical refining of used engine oil E_6.The viscosity and flash point of refined oils were in the range of 48.5 to 61.0 cst at 40°C and from 152°C to 210°C, respectively. The ash content of the refined oils was insignificant. The pour point under the best conditions of refining of E_6 was observed to be -12°C. Total (organic) acidity was in the range of 0.038 to 0.044 mg KOH/g of oil whereas the inorganic acidity was nil.

Table 4.8 shows the improvement in colour of the refined oils from [+4.5 to +2.5], [+5.5 to +3.0] and [+4.0 to + 2.0] ASTM units on treatment with [50S 10 C], [60S 8C] and [60S 10C] at 250°C, 280°C and 300°C, respectively. The used lubricating oils samples are centrifuge up to 500 r.p.m. to 1500 r.p.m. The percent reduction in colour at 300° C over that at 250°C was 44, 45 and 50 for refined oils under the conditions of [50S 10C], [60S 8C] and [60S 10C], respectively. The colour and yield were good for [60S 10C] refined oils,

therefore, this treatment can be applied for satisfactory and economical refining of used engine oil E_7. The viscosity and flash point of refined oils were in the range of 53.5 to 69.0 cst at 40°C and from 165°C to 215°C, respectively. The ash content was insignificant. The pour point under the best conditions of refining of E_7 was observed to be -6°C. Total (organic) acidity was in the range of 0.027 to 0.34 mg KOH/g of oil whereas the inorganic acidity was nil.

Table 4.9 shows the improvement in colour of the refined oils from [+5.0 to +3.0], [+6.5 to +3.5] and [+4.5 to + 2.0] ASTM units on treatment with [50S 10C], [60S 8C] and [60S 10C] at 250°C, 280°C and 300°C, respectively. The used lubricating oils samples are centrifuge up to 500 r.p.m. to 1500 r.p.m. The percent reduction in colour at 300°C over that at 250°C was 44, 46 and 56 for refined oils under the conditions of [50S 10C], [60S 8C] and [60S 10C], respectively. The colour and yield were good for [60S 10C] refined oils, therefore, this treatment can be applied for satisfactory and economical refining of used engine oil E_8. The viscosity and flash point of refined oils were in the range of 45.5 to 70.0 cst at 40°C and from 155°C to 207°C, respectively. The ash content was insignificant. The pour point under the best conditions of refining of E_8 was observed to be -7°C. Total (organic) acidity was in the range of 0.040 to 0.045 mg KOH/g of oil whereas the inorganic acidity was nil.

Table 4.10 shows the improvement in colour of the refined oils from [+5.0 to +3.0], [+6.0 to +3.5] and [+4.5 to + 2.0] ASTM units on treatment with [50S 10C], [60S 8C] and [60S 10C] at 250°C, 280°C and 300°C, respectively. The percent reduction in colour at 300°C over that at 250°C was 40, 42 and 33 for refined oils under the conditions of [50S 10C], [60S 8C] and [60S 10C], respectively. The used lubricating oils samples are centrifuge up to 500 r.p.m.

to 1500 r.p.m. The colour and yield were good for [60S 10C] refined oils, therefore, this treatment can be applied for satisfactory and economical refining of used engine oil E_9.The viscosity and flash point of refined oils were in the range of 58.5 to 88.0 cst at 40°C and from 195°C to 215°C, respectively. The ash content was insignificant. The pour point under the best conditions of refining of E_9 was observed to be -6°C. Total (organic) acidity was in the range of 0.036 to 0.040 mg KOH/g of oil whereas the inorganic acidity was nil.

Table 4.11 shows the improvement in colour of the refined oils from [+4.5 to +2.0], [+5.0 to +3.5] and [+3.5 to + 2.0] ASTM units on treatment with [50S 10 C], [60S 8C] and [60S 10C] at 250°C, 280°C and 300°C, respectively. The used lubricating oils samples are centrifuge up to 500 r.p.m. to 1500 r.p.m. The percent reduction in colour at 300°C over that at 250°C was 56, 30 and 43 for refined oils under the conditions of [50S 10C], [60S 8C] and [60S 10C], respectively. The colour and yield were good for [50S 10C] and [60S 10C] refined oils, therefore, this treatment can be applied for satisfactory and economical refining of used engine oil E_{10}.The viscosity and flash point of refined oils were in the range of 61.5 to 84.5 cst at 40°C and from 198°C to 220°C, respectively. The ash content was insignificant. The pour point under the best conditions of refining of E_{10} was observed to be -7°C. Total (organic) acidity was in the range of 0.034 to 0.038 mg KOH/g of oil whereas the inorganic acidity was nil.

4.4.2 Gear Oils

The five samples used gear oils treated with 30, 40 and 50 % 1-butanol were subjected to clay treatment with 4.0, 5.0 and 6.0 % (w/v) of fuller's earth. The

above quantity of clay treatment of clay was chosen for reasons that below 4.0 % level of clay, solvent treated oils were not showing appreciable improvement in color values, Moreover, above 6.0 % use of clay, 1-butanol treated oils were not showing much improvement in colour besides the yield was also getting decreased, therefore, it was not economical to use clay above 6.0 %. Clay treatment of solvent treated oils was carried on at 300°C because of high efficiency of bleaching with fuller's earth at this temperature which was also observed in case of engine oils. However, on further increase in temperature beyond 300°C there was not significant improvement in colour.

Tables 4.13 to 4.17 show the effect of percentage of clay on the colour, viscosity, flash point, pour point and ash content of the refined oils. With increase in quantity of clay the viscosity was observed to increase and the colour of refined oils also improved. Decrease in ash content shows the proper refining since more ash content in used gear oil samples was due to the presence of the blended additives and carbon particles which have been removed in the process of refining.

Table 4.13 Characteristics of Base Stocks Prepared From G_1

Property/test	G_1 Refined with 30 % 1- butanol and			G_1 Refined with 40% 1- butanol and			G_1 Refined with 50% 1- butanol and		
	4% Clay	5% Clay	6% Clay	4% Clay	5% Clay	6% Clay	4% Clay	5% Clay	6% Clay
1. Colour	+5.0	+5.0	+4.5	+4.5	+3.5	+3.0	+4.5	+3.0	+2.5
2. Viscosity (cst) at 40°C	154.4	155.0	155.4	155.8	156.2	156.5	157.0	157.5	158.0
3. Flash Point (°C)	220	220	220	221	220	222	220	221	220
4. Pour Point (°C)	-8	-8	-8	-8	-8	-8	-8	-8	-8
5. Ash Content (%)	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004
6. Acidity (mg KOH/g of oil) a. Inorganic b. Organic	 Nil 0.041	 Nil 0.040	 Nil 0.038	 Nil 0.045	 Nil 0.043	 Nil 0.040	 Nil 0.046	 Nil 0.043	 Nil 0.041
7. Corrosion, Copper Strip 3h at 100°C	1b	1b	1b	2a	1b	1b	2a	1b	1b
8. Yield of Refined Oil (%)	86.0	85.5	85.0	85.0	84.0	83.5	84.5	84.0	83.0

Table 4.14 Characteristics of Base Stocks Prepared From G_2

Property/test	G_2 Refined with 30% 1- butanol and			G_2 Refined with 40% 1- butanol and			G_2 Refined with 50% 1- butanol and		
	4% Clay	5% Clay	6% Clay	4% Clay	5% Clay	6% Clay	4% Clay	5% Clay	6% Clay
1. Colour	+5.5	+5.0	+4.5	+4.5	+3.5	+2.5	+4.5	+3.0	+2.0
2. Viscosity (cst) at 40°C	200.5	201.0	201.5	202.4	203.0	203.5	204.0	204.5	205.0
3. Flash Point (°C)	224	225	225	226	225	227	225	225	226
4. Pour Point (°C)	-10	-10	-10	-10	-10	-10	-10	-10	-10
5. Ash Content (%)	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005
6. Acidity (mg KOH/g of oil) a. Inorganic b. Organic	 Nil 0.033	 Nil 0.031	 Nil 0.030	 Nil 0.035	 Nil 0.034	 Nil 0.032	 Nil 0.038	 Nil 0.036	 Nil 0.035
7. Corrosion, Copper Strip 3h at 100°C	1b	1a	1a	1b	1b	1a	1b	1b	1b
8. Yield of Refined Oil (%)	81.5	82.5	81.0	83.0	82.5	81.5	81.5	83.0	81.0

Table 4.15 Characteristics of Base Stocks Prepared From G_3

Property/test	G_3 Refined with 30% 1- butanol and			G_3 Refined with 40% 1- butanol and			G_3 Refined with 50% 1- butanol and		
	4% Clay	5% Clay	6% Clay	4% Clay	5% Clay	6% Clay	4% Clay	5% Clay	6% Clay
1. Colour	+5.5	+4.5	+3.5	+4.5	+3.0	+2.0	+5.0	+3.5	+2.5
2. Viscosity (cst) at 40°C	230.2	230.5	231.2	231.8	232.4	232.6	233.6	234.0	234.5
3. Flash Point (°C)	232	230	231	230	233	232	231	232	231
4. Pour Point (°C)	-11	-11	-11	-11	-11	-11	-11	-11	-11
5. Ash Content (%)	0.004	0.004	0.004	0.005	0.005	0.005	0.005	0.004	0.004
6. Acidity (mg KOH/g of oil) a. Inorganic b. Organic	Nil 0.036	Nil 0.033	Nil 0.032	Nil 0.038	Nil 0.036	Nil 0.035	Nil 0.039	Nil 0.038	Nil 0.037
7. Corrosion, Copper Strip 3h at 100°C	1b	1a	1a	1b	1b	1b	1b	1b	1b
8. Yield of Refined Oil (%)	82.0	81.5	81.0	81.5	83.5	83.0	83.0	82.5	82.0

Table 4.16 Characteristics of Base Stocks Prepared From G_4

Property/test	G_4 Refined with 30% 1- butanol and			G_4 Refined with 40% 1- butanol and			G_4 Refined with 50% 1- butanol and		
	4% Clay	5% Clay	6% Clay	4% Clay	5% Clay	6% Clay	4% Clay	5% Clay	6% Clay
1. Colour	+4.5	+3.5	+3.0	+4.5	+3.0	+2.5	+3.5	+3.0	+2.0
2. Viscosity (cst) at 40°C	273.8	274.0	274.5	275.0	275.5	276.0	276.5	277.2	277.6
3. Flash Point (°C)	234	234	234	235	234	234	233	234	233
4. Pour Point (°C)	-7	-7	-7	-7	-7	-7	-7	-7	-7
5. Ash Content (%)	0.005	0.005	0.005	0.005	0.004	0.004	0.005	0.004	0.004
6. Acidity (mg KOH/g of oil) a. Inorganic b. Organic	 Nil 0.039	 Nil 0.037	 Nil 0.036	 Nil 0.041	 Nil 0.040	 Nil 0.038	 Nil 0.042	 Nil 0.040	 Nil 0.039
7. Corrosion, Copper Strip 3h at 100°C	1b	1b	1b	1b	1b	1b	1b	1b	1b
8. Yield of Refined Oil (%)	81.5	83.0	83.5	81.0	81.5	82.0	81.0	83.0	82.0

Table 4.17 Characteristics of Base Stocks Prepared From G_5

Property/test	G_5 Refined with 30 % 1- butanol and			G_5 Refined with 40% 1- butanol and			G_5 Refined with 50% 1- butanol and		
	4% Clay	5% Clay	6% Clay	4% Clay	5% Clay	6% Clay	4% Clay	5% Clay	6% Clay
1. Colour	+5.5	+4.5	+4.0	+4.5	+3.0	+2.0	+4.0	+3.0	+2.0
2. Viscosity (cst) at 40°C	330.4	330.8	331.2	332.6	332.8	332.2	333.4	333.8	334.0
3. Flash Point (°C)	235	234	233	235	234	235	232	234	235
4. Pour Point (°C)	-6	-6	-6	-6	-6	-6	-6	-6	-6
5. Ash Content (%)	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004
6. Acidity (mg KOH/g of oil) a. Inorganic b. Organic	Nil 0.031	Nil 0.029	Nil 0.028	Nil 0.033	Nil 0.031	Nil 0.030	Nil 0.035	Nil 0.033	Nil 0.031
7. Corrosion, Copper Strip 3h at 100°C	1a	1a	1a	1b	1a	1a	1b	1b	1b
8. Yield of Refined Oil (%)	82.5	82.0	82.0	81.5	80.0	79.0	79.5	81.0	81.5

Table 4.13 shows the improvement in colour after 4 to 6 % clay treatment from [+5.0 to +2.5] ASTM units for 30 to 50 % 1-butanol treated oils at 300°C.The percent reduction in colour for 6 % clay over that for 4 % clay was 10, 33 and 44 for the 30, 40, and 50 % 1-butanol treated oils, respectively. The colour and yield were approximately same for oils treated under [40S 5C], [40S 6C], [50S 5C] and [50S 6C] conditions at 300°C .Therefore, any one of these treatment can be applied for satisfactory and economical refining of used engine oil G_1. The viscosity and flash point of refined oils were in the range of 154.4 to 158.0 cst at 40°C and from 220°C to 222°C, respectively. The ash content of the refined oil was insignificant indicating better processing. The pour point was observed to be -8°C. Total (organic) acidity was in the range of 0.038 to 0.046 mg KOH/g of oil whereas the inorganic acidity was nil.

Table 4.14 shows the improvement in colour after 4 to 6 % clay treatment from [+5.5 to +2.5] ASTM units for 30 to 50 % 1-butanol treated oils at 300°C .The percent reduction in colour for 6 % clay over that for % was 18, 45 and 56 for the 30, 40 and 50% 1-butanol treated oils, respectively. The colour and yield were more or less for [40S 5C], [40S 6C], [50S 5C] and [50S 6C] conditions at 300°C. Therefore, any one of these treatment can be applied for satisfactory and economical refining of used engine oil G_2.The viscosity and flash point of refined oils were in the range of 200.5 to 205.0 cst at 40°C and from 224°C to 227°C, respectively. The ash content of the refined oil was insignificant. The pour point was observed to be -10°C. Total (organic) acidity was in the range of 0.030 to 0.038 mg KOH/g of oil whereas the inorganic acidity was nil.

Table 4.15 shows the improvement in colour after 4 to 6 % clay treatment from [+5.5 to +2.5] ASTM units for 30 to 50 % 1-butanol treated oils at 300°C .The percent reduction in colour for 6 % clay over that for 4% clay was 36, 56 and 50 for the 30, 40 and 50 % 1-butanol treated oils, respectively. The colour and yield were good for [40S 5C], [50S 6C] conditions, therefore, both the treatment can be applied for satisfactory and economical refining of used engine oil G_3. The viscosity and flash point of refined oils were in the range of 230.2 to 234.5 cst at 40°C and from 230°C to 233°C, respectively. The ash content was insignificant. The pour point was observed to be -11°C. Total (organic) acidity was in the range of 0.032 to 0.039 mg KOH/g of oil whereas the inorganic acidity was nil.

Table 4.16 shows the improvement in colour after 4 to 6 % clay treatment from [+4.5 to +2.0] ASTM units for 30 to 50 % 1-butanol treated oils, respectively at 300°C .The percent reduction in colour for 6 % clay over that for 4 % clay was 33, 44 and 43 for the 30, 40 and 50% 1-butanol treated oils, respectively. The colour and yield were good for [30S 6C], [40S 5C], [50S 6C] and [50S 6C] conditions, at 300°C. Therefore, any one of these treatment can be applied for satisfactory and economical refining of used engine oil G_4.The viscosity and flash point of refined oils were in the range of 273.8 to 277.6 cst at 40°C and from 233°C to 235°C, respectively. The ash content was insignificant. The pour point was observed to be -11°C. Total (organic) acidity was in the range of 0.036 to 0.042 mg KOH/g of oil whereas the inorganic acidity was nil.

Table 4.17 shows the improvement in colour after 4 to 6 % clay treatment from [+5.5 to +2.0] ASTM units for 30 to 50% 1-butanol treated oils. The percent reduction in colour for 6 % clay over that for 4 % clay was 27, 56 and 50 for

the 30, 40 and 50 % 1-butanol treated oils, respectively. The colour and yield were good for [40S 5C], [50S 6C] and [50S 6C] conditions, at 300°C respectively. Therefore, any one of these treatment can be applied for satisfactory and economical refining of used engine oil G_5.The viscosity and flash point of refined oils were in the range of 330.4 to 334.0 cst at 40°C and from 232°C to 235°C, respectively. The pour point was observed to be -6°C. The ash content was insignificant. Total (organic) acidity was in the range of 0.028 to 0.035 mg KOH/g of oil whereas the inorganic acidity was nil.

4.4.3 Compressor Oils

The three used compressor oil samples treated with 30, 35 and 40 % 1-butanol were further subjected to clay treatment with 4.0, 5.0 and 6.0 % fuller's earth (w/v). The above quantity of clay was chosen for reasons that below 4.0 % level of clay; 1-butanol treated oils were not showing appreciable bleaching. Moreover, above 6.0 percent use of clay, solvent treated oils were not showing much improvement in colour besides the yield was also getting affected, therefore, it was not considered economical to use clay above 6.0 %.

Tables 4.19 to 4.21 show the effect of percentage of clay on colour, viscosity, flash point, pour point and ash content of the refined oils. With increase in quantity of clay, the viscosity was observed to increase and the colour of refined oils also improved. Decrease in ash content shows the proper refining since more ash content in used compressor oil samples was due to the presence of the blended additives and carbon particles which have been removed in the process of refining. All the samples of base stocks prepared from different compressor oils passed the corrosion copper strip test.

Table 4.19 Characteristics of Base Stocks Prepared From C_1

Property/test	C_1 Refined with 30 % 1- butanol and			C_1 Refined with 35 % 1- butanol and			C_1 Refined with 40 % 1- butanol and		
	4% Clay	5% Clay	6% Clay	4% Clay	5% Clay	6% Clay	4% Clay	5% Clay	6% Clay
1. Colour	+3.0	+2.5	+2.0	+2.5	+1.5	+1.0	+2.0	+1.5	+1.0
2. Viscosity (cst) at 40°C	30.0	30.5	31.0	31.5	32.5	33.0	33.0	33.5	34.0
3. Flash Point (°C)	164	164	164	165	164	164	164	165	165
4. Pour Point (°C)	-30	-30	-30	-30	-30	-30	-30	-30	-30
5. Ash Content (%)	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004
6. Acidity (mg KOH/g of oil) a. Inorganic b. Organic	 Nil 0.030	 Nil 0.029	 Nil 0.029	 Nil 0.033	 Nil 0.032	 Nil 0.031	 Nil 0.035	 Nil 0.033	 Nil 0.032
7. Corrosion, Copper Strip 3h at 100°C	1a	1a	1a	1a	1a	1a	1b	1b	1b
8. Yield of Refined Oil (%)	81.4	80.6	79.0	81.0	80.5	82.5	78.6	79.0	77.5

Table 4.20 Characteristics of Base Stocks Prepared From C_2

Property/test	C_2 Refined with 30% 1-butanol and			C_2 Refined with 35 % 1-butanol and			C_2 Refined with 40% 1-butanol and		
	4% Clay	5% Clay	6% Clay	4% Clay	5% Clay	6% Clay	4% Clay	5% Clay	6% Clay
1. Colour	+3.0	+2.0	+2.0	+2.5	+2.0	+1.0	+2.0	+1.5	+1.0
2. Viscosity (cst) at 40°C	41.0	41.5	42.0	42.5	43.0	43.5	43.5	44.0	44.5
3. Flash Point (°C)	170	168	169	169	170	169	169	169	169
4. Pour Point (°C)	-27	-27	-27	-27	-27	-27	-27	-27	-27
5. Ash Content (%)	0.003	0.003	0.002	0.003	0.003	0.002	0.003	0.002	0.002
6. Acidity (mg KOH/g of oil) a. Inorganic b. Organic	 Nil 0.036	 Nil 0.035	 Nil 0.034	 Nil 0.038	 Nil 0.037	 Nil 0.035	 Nil 0.040	 Nil 0.038	 Nil 0.037
7. Corrosion, Copper Strip 3h at 100°C	1b	1b	1b	1b	1b	1b	1b	1b	1b
8. Yield of Refined Oil (%)	82.0	82.5	81.0	82.0	83.5	82.0	83.5	83.5	84.0

Table 4.21 Characteristics of Base Stocks Prepared From C_3

Property/test	C_3 Refined with 30% 1-butanol and			C_3 Refined with 35 % 1-butanol and			C_3 Refined with 40 %1-butanol and		
	4% Clay	5% Clay	6% Clay	4% Clay	5% Clay	6% Clay	4% Clay	5% Clay	6% Clay
1. Colour	+2.5	+2.0	+2.0	+2.0	+1.5	+1.0	+2.0	+1.5	+1.0
2. Viscosity (cst) at 40°C	61.5	62.0	62.5	62.5	63.0	63.5	64.0	64.5	65.0
3. Flash Point (°C)	174	174	174	174	173	173	173	174	174
4. Pour Point (°C)	-27	-27	-27	-27	-27	-27	-27	-27	-27
5. Ash Content (%)	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.004	0.004
6. Acidity (mg KOH/g of oil) a. Inorganic b. Organic	 Nil 0.028	 Nil 0.026	 Nil 0.025	 Nil 0.031	 Nil 0.030	 Nil 0.030	 Nil 0.033	 Nil 0.031	 Nil 0.029
7. Corrosion, Copper Strip 3h at 100°C	1b	1b	1b	1b	1b	1b	1b	1b	1b
8. Yield of Refined Oil (%)	81.5	82.0	80.5	80.0	82.5	80.0	78.0	77.5	81.0

Table 4.19 shows the improvement in colour after 4 to 6 % clay treatment from [+3.0 to +1.0] ASTM units for 30 to 40 % 1-butanol treated oils at 200°C .The percent reduction in colour for 6 % clay over that for 4 % clay was 33, 60 and 50 for the 30, 35 and 40 % 1-butanol treated oils, respectively. The colour and yield were approximately same for oils treated under [35S 5C], [35S 6C], [40S 5C] and [40S 6C] conditions at 200°C.Therefore, any one of these treatment can be applied for satisfactory and economical refining of C_1. The viscosity and flash point of refined lubricating oils with 1- butanol were in the range of 30.0 to 34.0 cst at 40°C and from 164°C to 165°C, respectively. The ash content of the refined oil was insignificant indicating better processing. The pour point was observed to be -30°C. Total (organic) acidity was in the range of 0.029 to 0.035 mg KOH/g of oil whereas the inorganic acidity was nil.

Table 4.20 shows the improvement in colour after 4 to 6 % clay treatment from [+3.0 to +1.0] ASTM units for 30 to 40 % 1-butanol treated lubricating oils at 200°C .The percent reduction in colour for 6 % clay over that for 4 % clay was 33, 60 and 50 for the 30, 35 and 40 % 1-butanol treated oils, respectively. The colour and yield were more or less same for oils treated under [35S 6C], [40S 5C], [40S 6C] conditions at 200°C. Therefore, any one of these treatment can be applied for satisfactory and economical refining of C_2. The viscosity and flash point of refined oils were in the range of 41.0 to 44.5 cst at 40°C and from 168°C to 170°C, respectively. The ash content of the refined oil was insignificant indicating better processing. The pour point was observed to be -27°C. Total (organic) acidity was in the range of 0.034 to 0.040 mg KOH/g of oil whereas the inorganic acidity was nil.

Table 4.21 shows the improvement in colour after 4 to 6 % clay treatment from [+2.5 to +1.0] ASTM units for 30 to 40 % 1-butanol treated oils at 200°C. The percent reduction in colour for 6 % clay over that for 4 % clay was 20, 40 and 50 for the 30, 35 and 40 % 1-butanol treated oils, respectively. The colour and yield were more or less same for oils treated under [35S 5C], [35S 6C], [40S 5C] and [40S 6C] conditions at 200°C, therefore, any one of these treatment can be applied for satisfactory and economical refining of C_3.The viscosity and flash point of refined oils were in the range of 61.5 to 65.0 cst at 40°C and from 173°C to 174°C, respectively. The ash content of the refined oil was insignificant .The pour point was observed to be -27°C. Total (organic) acidity was in the range of 0.025 to 0.033 mg KOH/g of oil whereas the inorganic acidity was nil.

4.4.4 Hydraulic oils

The five samples used hydraulic oils treated with 20, 30 and 35 % 1-butanol were further subjected to clay treatment with 4.0, 5.0 and 6.0 % fuller's earth (w/v). The above quantity of clay was chosen for reasons that below 4.0 % level of clay; 1-butanol treated oils were not showing appreciable improvement in colour values. Moreover, above 6.0 % use of clay, 1-butanol treated oils were not showing much improvement in colour besides the yield was also getting decreased, therefore, it was not considered economical to use clay above 6.0 %.

Tables 4.23 to 4.27 show the effect of percentage of clay on colour, viscosity, flash point, pour point and ash content of the refined oils. With increase in quantity of clay, the viscosity was observed to increase and the colour of refined oils also improved. Decrease in ash content shows the proper refining

since more ash content in used compressor oil samples was due to the presence of the blended additives and carbon particles which have been removed in the process of refining. All the samples of base stocks prepared from different compressor oils passed the corrosion copper strip test.

Table 4.23 Characteristics of Base Stocks Prepared From H_1

Property/test	H_1 Refined with 25% 1-butanol and			H_1 Refined with 30% 1- butanol and			H_1 Refined with 35% 1-butanol and		
	4% Clay	5% Clay	6% Clay	4% Clay	5% Clay	6% Clay	4% Clay	5% Clay	6% Clay
1. Colour	+2.5	+2.0	+2.0	+2.5	+2.0	+2.0	+2.0	+1.5	+1.5
2. Viscosity (cst) at 40°C	45.0	45.5	46.0	46.0	46.5	46.5	47.0	47.5	48.0
3. Flash Point (°C)	195	196	195	196	196	195	195	196	196
4. Pour Point (°C)	-8	-8	-8	-8	-8	-8	-8	-8	-8
5. Ash Content (%)	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil
6. Acidity (mg KOH/g of oil) a. Inorganic b. Organic	Nil 0.035	Nil 0.033	Nil 0.030	Nil 0.036	Nil 0.035	Nil 0.033	Nil 0.038	Nil 0.036	Nil 0.035
7. Corrosion, Copper Strip 3h at 100°C	1b	1a	1a	1b	1b	1a	1b	1a	1a
8. Yield of Refined Oil (%)	81.0	82.5	81.5	81.6	82.0	78.5	79.5	77.0	81.5

Table 4.24 Characteristics of Base Stocks Prepared From H_2

Property/test	H_2 Refined with 25 % 1-butanol and			H_2 Refined with 30% 1-butanol and			H_2 Refined with 35% 1-butanol and		
	4% Clay	5% Clay	6% Clay	4% Clay	5% Clay	6% Clay	4% Clay	5% Clay	6% Clay
1. Colour	+3.0	+2.5	+2.5	+2.0	+2.0	+1.5	+2.0	+1.5	+1.5
2. Viscosity (cst) at 40°C	71.0	71.0	71.5	72.07	72.0	72.5	73.0	73.5	74.0
3. Flash Point (°C)	209	210	210	210	210	211	210	211	210
4. Pour Point (°C)	-5	-5	-5	-5	-5	-5	-5	-5	-5
5. Ash Content (%)	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil
6. Acidity (mg KOH/g of oil) a. Inorganic b. Organic	 Nil 0.036	 Nil 0.034	 Nil 0.033	 Nil 0.037	 Nil 0.036	 Nil 0.034	 Nil 0.038	 Nil 0.035	 Nil 0.033
7. Corrosion, Copper Strip 3h at 100°C	1b	1b	1b	1b	1a	1a	1b	1b	1b
8. Yield of Refined Oil (%)	76.4	76.0	81.6	81.5	80.3	81.0	78.5	78.2	78.8

Table 4.25 Characteristics of Base Stocks Prepared From H_3

Property/test	H_3 Refined with 25 % 1-butanol and			H_3 Refined with 30% 1- butanol and			H_3 Refined with 35% 1- butanol and		
	4% Clay	5% Clay	6% Clay	4% Clay	5% Clay	6% Clay	4% Clay	5% Clay	6% Clay
1. Colour	+3.5	+3.5	+3.0	+2.5	+2.5	+2.0	+2.5	+2.0	+2.0
2. Viscosity (cst) at 40°C	122.0	122.5	123.0	123.5	123.5	124.0	124.5	125.0	125.5
3. Flash Point (°C)	218	218	219	219	220	219	220	219	220
4. Pour Point (°C)	-5	-5	-5	-5	-5	-5	-5	-5	-5
5. Ash Content (%)	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil
6. Acidity (mg KOH/g of oil) a. Inorganic b. Organic	Nil 0.043	Nil 0.041	Nil 0.040	Nil 0.045	Nil 0.044	Nil 0.042	Nil 0.045	Nil 0.043	Nil 0.040
7. Corrosion, Copper Strip 3h at 100°C	1b	1b	1b	1b	1b	1b	1b	1b	1b
8. Yield of Refined Oil (%)	78.2	78.0	81.5	81.4	77.0	78.0	78.8	81.5	81.1

Table 4.26 Characteristics of Base Stocks Prepared From H_4

Property/test	H_4 Refined with 25 % 1-butanol and			H_4 Refined with 30% 1-butanol and			H_4 Refined with 35% 1-butanol and		
	4% Clay	5% Clay	6% Clay	4% Clay	5% Clay	6% Clay	4% Clay	5% Clay	6% Clay
1. Colour	+3.5	+3.5	+2.5	+2.5	+2.0	+2.0	+2.5	+1.5	+1.5
2. Viscosity (cst) at 40°C	223.0	223.6	223.9	224.3	224.7	225.0	225.4	225.8	226.6
3. Flash Point (°C)	226	225	225	226	226	226	225	227	226
4. Pour Point (°C)	-3	-3	-3	-3	-3	-3	-3	-3	-3
5. Ash Content (%)	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil
6. Acidity (mg KOH/g of oil) a. Inorganic b. Organic	 Nil 0.032	 Nil 0.031	 Nil 0.030	 Nil 0.034	 Nil 0.032	 Nil 0.030	 Nil 0.035	 Nil 0.033	 Nil 0.030
7. Corrosion, Copper Strip 3h at 100°C	1a	1a	1a	1b	1a	1b	1b	1a	1a
8. Yield of Refined Oil (%)	81.2	78.0	78.0	81.6	80.2	80.0	81.4	82.0	81.2

Table 4.27 Characteristics of Base Stocks Prepared From H_5

Property/test	H_5 Refined with 25 % 1- butanol and			H_5 Refined with 30% 1-butanol and			H_5 Refined with 35 % 1- butanol and		
	4% Clay	5% Clay	6% Clay	4% Clay	5% Clay	6% Clay	4% Clay	5% Clay	6% Clay
1. Colour	+3.5	+3.0	+2.5	+2.0	+2.0	+1.5	+2.5	+2.5	+1.5
2. Viscosity (cst) at 40°C	333.0	333.4	333.7	334.2	334.5	335.0	335.5	335.8	336.0
3. Flash Point (°C)	228	228	228	228	229	228	229	228	228
4. Pour Point (°C)	-5	-5	-5	-5	-5	-5	-5	-5	-5
5. Ash Content (%)	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003
6. Acidity (mg KOH/g of oil) a. Inorganic b. Organic	 Nil 0.032	 Nil 0.031	 Nil 0.028	 Nil 0.031	 Nil 0.029	 Nil 0.028	 Nil 0.033	 Nil 0.031	 Nil 0.030
7. Corrosion, Copper Strip 3h at 100°C	1b	1b	1a	1b	1a	1a	1b	1a	1a
8. Yield of Refined Oil (%)	81.2	80.0	79.5	78.5	79.2	77.0	78.0	78.8	79.0

Table 4.23 shows the improvement in colour after 4 to 6 % clay treatment from [+2.5 to +1.5] ASTM units for 25 to 35 % 1-butanol treated oils at 200°C .The percent reduction in colour for 6 % clay over that for 4 % clay was 20, 22 and 25 for the 25, 30 and 35 % solvent treated oils, respectively. The colour and yield were approximately same for oils treated under [35S 5C], and [35S 6C] conditions at 250°C. Therefore, both the treatment can be applied for satisfactory and economical refining of H_1. The viscosity and flash point of refined oils were in the range of 45.0 to 48.0 cst at 40°C and from 190°C to 196°C, respectively. The ash content of the refined oil was nil. The pour point was observed to be -8°C. Total (organic) acidity was in the range of 0.030 to 0.038 mg KOH/g of oil whereas the inorganic acidity was nil.

Table 4.24 shows the improvement in colour after 4 to 6 % clay treatment from [+3.0 to +1.5] ASTM units for 25 to 35 % 1-butanol treated oils at 250°C .The percent reduction in colour for 6 % clay over that for 4 % clay was 17, 20 and 25 for the 25, 30 and 35 % 1-butanol treated oils, respectively. The colour and yield were approximately same for oils treated under [30S 6C], [35S 5C] and [35S 6C] conditions at 250°C. Therefore, any one of these treatment can be applied for satisfactory and economical refining of H_2. The viscosity and flash point of refined oils were in the range of 71.0 to 74.0 cst at 40°C and from 209°C to 211°C, respectively. The ash content of the refined oil was nil. The pour point was observed to be -5°C. Total (organic) acidity was in the range of 0.033 to 0.038 mg KOH/g of oil whereas the inorganic acidity was nil.

Table 4.25 shows the improvement in colour after 4 to 6 % clay treatment from [+3.0 to +2.0] ASTM units for 25 to 35 % 1-butanol treated oils at 250°C. The

percent reduction in colour for 6 percent clay over that for 4 % clay was 14, 20 and 25 for the 25, 30 and 35 % 1-butanol treated oils, respectively. The colour and yield were approximately same for oils treated under [30S 6C], [35S 5C] and [35S 6C] conditions at 250°C. Therefore, any one of these treatment can be applied for satisfactory and economical refining of H_3. The viscosity and flash point of refined oils were in the range of 122.0 to 125.5 cst at 40°C and from 218°C to 220°C, respectively. The ash content of the refined oil was nil. The pour point was observed to be -5°C. Total (organic) acidity was in the range of 0.040 to 0.045 mg KOH/g of oil whereas the inorganic acidity was nil.

Table 4.26 shows the improvement in colour after 4 to 6 % clay treatment from [+3.5 to +1.5] ASTM units for 25 to 35 % 1-butanol treated oils at 250°C. The percent reduction in colour for 6 % clay over that for 4 % clay was 29, 20 and 40 for the 25, 30 and 35 % 1-butanol treated oils, respectively. The colour and yield were approximately same for oils treated under [35S 5C] and [35S 6C] conditions at 250°C. Therefore, both the treatments can be applied for satisfactory and economical refining of H_4. The viscosity and flash point of refined oils were in the range of 223.0 to 226.6 cst at 40°C and from 225°C to 227°C, respectively. The ash content of the refined oil was nil. The pour point was observed to be -3°C. Total (organic) acidity was in the range of 0.030 to 0.035 mg KOH/g of oil whereas the inorganic acidity was nil.

Table 4.27 shows the improvement in colour after 4 to 6 % clay treatment from [+3.5 to +1.5] ASTM units for 25 to 35 % 1-butanol treated oils at 250°C. The percent reduction in colour for 6 % clay over that for 4 % clay was 19, 25 and 40 for the 25, 30 and 35 % 1-butanol treated oils, respectively. The colour and yield were better for [35S 6C] conditions in comparison to other refined oils.

Therefore, both the treatments can be applied for satisfactory and economical refining of H_5. The viscosity and flash point of refined oils were in the range of 333.0 to 336.6 cst at 40°C and from 228°C to 229°C, respectively. The ash content of the refined oil was nil. The pour point was observed to be -5°C. Total (organic) acidity was in the range of 0.028 to 0.033 mg KOH/g of oil whereas the inorganic acidity was nil.

4.5 EFFECT OF ADDITIVE BLENDING ON THE PROPERTIES OF REFINED BASE STOCKS

The base stocks obtained from refining followed by solvent extraction and clay treatment of used lubricating oils namely; engine, gear, compressor and hydraulic oils which were having different physico-chemical characteristics were used to prepare various grades of finished oils obtained by blending of additives blended. Mono and multi grades of engine oils available in the market for various purposes, require different base stocks depending upon their characteristics. Further, a specific amount of suitable additive is needed for a particular grade of oil. As it is very difficult to prepare specific base stock requirement for gear oil, compressor oil and hydraulic oils, these base stocks were prepared by refining of used lubricating oils. The standard additives for engine, gear, compressor and hydraulic oils were procured and their specific percentage as per requirements of were blended with the prepared base stocks to make a particular grade of either of the above oils. These oils were characterized for different properties and compared with BIS specifications. The results of blending have been shown in Tables 4.28 to 4.33

4.5.1 Engine Oils

The ten samples of engine oils were prepared and characterized for various properties such as viscosity at 40°C and 100°C, viscosity index, flash point, pour point, inorganic and total acidity and ash content which are depicted in Table 4.28. The grade of the oil after blending of the additives has also been shown in the Table by comparing their characteristics with that of BIS specification. All the samples of finished oils prepared from different base stocks passed the corrosion strip test.

To make the engine oil the base stocks prepared from E_1, E_3, E_4, E_6, E_{10} having viscosities of 56.0 and 57.0 (both for E_1) , 64.0, 65.5, 61.0 and 84.5 cst at 40°C , respectively were considered suitable as the viscosities of these base stocks were appropriate to prepare engine oil. A certain percent of polyisobutylene and Molybdenum disulfide have been added to upgrade the quality of oil in terms of corrosion resistance, rust prevention, oxidation inhibition etc. After using different proportion of additives in the base stocks prepared from E_1 and E_6 it was concluded by addition of 5.8 % Molybdenum disulfide and 5.2 % polyisobutylene were meeting the requirement of the specification for this grade. Similarly, addition of 5.0 % polyisobutylene and 5.2 % Molybdenum disulfide was observed to the optimum for getting SAE 30 grade oil from base stock prepared from E_3 and E_4 .The quantity needed of Molybdenum disulfide has been observed to be lower in this case as the viscosity for base stocks prepared from E_3 and E_4 was higher than that for the base stocks prepared from E_1 and E_6.. For base stock prepared from E_{10} Molybdenum disulfide was not at all required and only 5.2 % polyisobutylene was added to obtain SAE 30 grade engine oil for reason that the viscosity of base stock itself was failing in the limits prescribed for SAE 30 grade oil.

As shown in Table 4.28, the viscosity of the engine oil of SAE 30 grade prepared from different base stocks at 40°C and 100°C was increased after additives blending and varied from 83.0 to 92.0 cst and from 10.5 to 12.0 cst, respectively ; the viscosity index for these finished oils varied from 112 to 118. The flash point of the finished oils was in the range of 204°C to 221°C and the pour point varied between -6 to -15°C. As the finished oil was blended with additives, the ash content increased and was in the range of 0.0863 to 0.877 %. Total acidity was in the range of 0.019 to 0.026 mg KOH /g of oil whereas the inorganic acidity was nil for all the finished oils.

Therefore, the oils thus prepared met the quality requirements of SAE 30 grade. To make the engine oil of SAE grade 40, the base stocks prepared from E_7, E_8 , E_9 having viscosities of 68.0, 70.0 and 88.0 cst at 40°C, respectively were considered suitable as the viscosities of these base stocks were appropriate to prepare SAE 40 grade of engine oil. A certain percent of polyisobutylene was added to upgrade the quality of oil. Simultaneously, proportion of Molybdenum disulfide was varied to obtain viscosity of the oil comparable to that of SAE 40 grade for which the viscosity at 100°C should be from 12.5 to 16.3 cst. After using different proportion of additives in the base stocks prepared from E_7 and E_8, it was concluded that for getting SAE 40 grade oil the results obtained by addition of 6.5 % Molybdenum disulfide and 5.2 % polyisobutylene were meeting the requirement of the specification for this grade. Similarly, addition of 5.0 % Molybdenum disulfide and 5.2 % polyisobutylene was observed to be optimum for getting SAE 40 grade oil from base stock prepared from E_9. The quantity needed of Molybdenum disulfide has been observed to be lower in this case as the viscosity for base stock prepared from E_9 was higher than that for the base stocks prepared from E_7 and E_8. For

base stock prepared from H_3, Molybdenum disulfide was not at all required for the reason that the viscosity of base stock itself was failing in the limits prescribed for SAE 40 grade oil. However only 5.2 % polyisobutylene was added to obtain SAE 40 grade engine oil to upgrade its quality. The finished engine oil SAE 40 grade prepared from different base stocks were having variation in their characteristics as shown in Table 4.28 but all these values were failing within the stipulated limits for SAE 40 grade. The viscosity at 40°C and 100°C was increased after additive blending and varied from 112.0 to 132.0 cst and from 13.5 to 14.0 cst, respectively; the viscosity index for these finished oils varied from 109 to 120. The flash point was in the range of 209°C to 221°C and the pour point varied between -6°C to -7°C.

As the finished oil contained additives the ash content increased and was in the range of 0.868 to 0.875 %. Total acidity was in the range of 0.018 to 0.022 mg KOH /g of oil whereas the inorganic acidity was nil for all the finished oils. Therefore, the oils thus prepared met the quality requirement of SAE 40 grade. SAE 40, 50 and 20W/40 grades of oils can also be prepared by blending different base stocks obtained from refining of various used oils as shown in Table 4.29 and 4.30. To make the engine oil of SAE 40, the base stocks from E_1, E_2, E_3, E_9 and E_{10} having viscosities of 57.0, 69.0 , 64.0 75.0 and 83.0 cst at 40°C were blended with other base stock prepared from H_5 having viscosity of 335.0 cst at 40°C resulting in the viscosities of mixed base stock from 115.0 to 127.7 cst at 40°C The blends of base stocks were also obtained from base stocks prepared from E_1, E_6, E_4 and E_7 having viscosities of 56.0, 61.0, 65.0 and 69.0 cst at 40°C and with other base stock prepared from G_5 having viscosity of 333.2 cst at 40°C resulting in the viscosities of mixed base stocks from 117.8 to 128.6 cst at 40°C. The mixed base stocks thus

obtained were considered suitable as the viscosities of these base stocks were appropriate to prepare SAE 40 grade of engine oil. A suitable percent of polyisobutylene was added to upgrade the quality of oil and a fixed percent of Molybdenum disulfide was also added for adjustment of viscosity in the prescribed range for respective grade of oil. The finished engine oils SAE 40 prepared from different mixed base stocks were having variation in their characteristics as shown in Table 4.29 and 4.30 but all these values were failing within the stipulated limits for SAE 40 grade oil. The viscosity was increased after additives blending and was observed to vary from 127.2 to 139.0 cst and from 13.0 to 14.5 cst at 40°C and 100°C, respectively, the viscosity index for these finished oils varied from 104 to 109. The flash point was in the range of 206°C to 220°C and pour point varied between -6°C to -15°C.

As the finished oil contained additives, the ash content increased and was in the range of 0.851 to 0.882 percent. Total acidity was in the range of 0.018 to 0.023 mg KOH/g of oil whereas the inorganic acidity was nil for all the finished oils Therefore, the oils thus prepared met the quality requirement of SAE 40 grade. To prepare the engine oil of SAE 50 grade the base stocks from E_{10} and E_9 having viscosities of 84.5 and 88.0 cst at 40°C were blended with other base stock prepared from H_5 having viscosity of 335.0 cst at 40°C resulting in the viscosities of mixed base stocks of 142.5 and 149.9 cst at 40°C. The blend of base stocks was also obtained from base stock prepared from E_9 having viscosity 88.0 cst at 40°C with other base stock prepared from G_5 having viscosity of 333.2 cst at 40°C resulting in the viscosity of mixed base stock of 148.6 cst at 40°C. The mixed base stocks thus obtained were considered suitable as the viscosities of engine oil.

Table 4.28 Characteristics of Finished Engine Oils

Base Stocks from oil	Viscosity of Base Stock at 40°C (cst)	Molybdenum disulfide (%)	Polyisobutylene (%)	Viscosity of Finished Oil (cst)		Viscosity Index	Flash Point (°C)	Pour Point (°C)	Ash Content (%)	Acidity (mg KOH/g of Oil)	
				At 40°C	At 100°C					Inorganic	Total
1. E_1	56.0	5.8	5.2	83.0	10.5	118	204	-15	0.872	Nil	0.026
2. E_1	57.0	5.8	5.2	85.8	11.0	115	204	-15	0.863	Nil	0.024
3. E_6	61.0	5.8	5.2	88.0	11.0	112	211	-8	0.868	Nil	0.019
4. E_3	64.0	5.0	5.2	88.0	11.5	116	207	-7	0.871	Nil	0.023
5. E_4	65.5	5.0	5.2	92.0	12.0	116	212	-6	0.877	Nil	0.021
6. E_7	68.0	6.5	5.2	112.0	13.5	120	215	-6	0.869	Nil	0.021
7. E_8	70.0	6.5	5.2	116.0	14.0	120	209	-7	0.868	Nil	0.022
8. E_{10}	84.5	5.8	5.2	92.0	11.5	116	221	-6	0.874	Nil	0.020
9. E_9	88.0	5.0	5.2	119.0	13.5	117	216	-6	0.875	Nil	0.018

As shown in Table 4.29 and Table 4.30, the viscosity of engine oil of SAE 50 grade was increased after additives blending and was observed to vary from 158.6 to 169.8 cst and 18.0 to 19.0 cst at 40°C and 100°C, respectively; the viscosity index of these finished oils varied from 118 to 120.The flash point was in the range of 214°C to 225°C and pour point varied between 6°C to -7°C. As the finished oil contained additives, the ash content increased and was in the range of 0.854 to 0.884 %.Total acidity was in the range of 0.014 to 0.021 mg KOH /g of oil whereas the inorganic acidity was nil. Therefore, the oils thus prepared were meeting the quality requirement of SAE 50 grade. The engine oils used in various types of automotive vehicles are expected to function smoothly under varying climate condition. Monograde of engine oils may not function smoothly under extremely opposite climatic conditions. Since these oils are having higher pour point they may cause ceasure of engine under the atmospheric temperature below its pour point. Therefore, specialty multigrade oils have been introduced by the standard manufacturers for their properties of having lower pour point and higher viscosity at 40°C and 100°C.

These multigrade oils can be used within a wide range of temperature. For preparing 20W/40 grade oil the base stock should have its low pour point. The base stocks resulting from refining of different used oils were not having low pour point except for base stock prepared from E_1 but the viscosity of this base stock was not suitable to prepare 20W/40 grade of oil, therefore, higher viscosity base stock was prepared from H_5 by blending E_1 and H_5 in 90 :10 proportion resulting in the viscosity of mixed base stock of 69.8 cst at 40°C. This mixed base stock thus obtained was considered suitable for preparing 20W/40 grade of engine oil. A fixed percent of polyisobutylene was added to

upgrade the quality of oil and 6.5 amount of Molybdenum disulfide was added for viscosity improvement. As shown in Table 4.29 the viscosity of the engine oil of 20W/ 40 grades was increased after additives blending to 112.0 and 15.0 cst at 40°C and 100°C, respectively; the viscosity index for this multigrade oil was 124. The flash point and pour point were 206°C and -16°C, respectively. As the finished oil was blended with additives, the ash content increased to 0.886 percent. Total acidity was 0.013 mg KOH / g of oil whereas the inorganic acidity was nil.

Table 4.29 Characteristics of Finished Engine Oils Prepared from Mixed Base Stocks

Base Stock From			Base Stock From			Viscosity of Mixed Base Stock at 40°C (cst)	Polyisobutylene (%)	Molybdenum disulfide (%)	Viscosity of Finished Oil (cst)		Viscosity Index	Flash Point (°C)	Pour Point (°C)	Ash Content (%)	Acidity (mg KOH/g of Oil)	
Oil	Viscosity at 40°C (cst)	% of Oil	Oil	Viscosity at 40°C (cst)	% of oil				At 40°C	At 100°C					Inorganic	Total
1. E_1	57.0	76	H_5	335.0	24	123.9	5.2	1.0	136.0	14.0	107	206	-13	0.874	Nil	0.021
2. E_2	69.0	78	H_5	335.0	22	127.7	5.2	1.0	139.0	14.5	109	214	-7	0.863	Nil	0.019
3. E_3	64.0	80	H_5	335.0	20	119.3	5.2	1.0	131.0	13.5	106	210	-7	0.873	Nil	0.021
4 E_9	75.0	84	H_5	335.0	16	115.3	5.2	1.0	127.8	13.0	105	210	-6	0.851	Nil	0.022
5 .E_{10}	83.0	88	H_5	335.0	12	115.0	5.2	1.0	127.2	13.0	105	212	-6	0.869	Nil	0.018
6 .E_{10}	84.5	78	H_5	335.0	22	142.5	5.2	1.0	158.6	18.0	119	214	-7	0.856	Nil	0.014
7. E_9	88.0	75	H_5	335.0	25	149.9	5.2	1.0	169.8	19.0	120	216	-6	0.854	Nil	0.021
8. E_1	57.0	90	H_5	335.0	10	69.8	5.2	1.0	112.0	15.0	124	206	-16	0.886	Nil	0.013

Table 4.30 Characteristics of Finished Lubricating Oils Prepared from Mixed Base Stocks

Base Stock From			Base Stock From			Viscosity of Mixed Base Stock at 40°C (cst)	Polyisobutylene (%)	Molybdenum disulfide (%)	Viscosity of Finished Oil (cst)		Viscosity Index	Flash Point (°C)	Pour Point (°C)	Ash Content (%)	Acidity (mg KOH/g of Oil)	
Oil	Viscosity at 40°C (cst)	% of Oil	Oil	Viscosity at 40°C (cst)	% of oil				At 40°C	At 100°C					Inorganic	Total
1. E_1	56.0	74	G_5	333.2	26	124.8	5.2	1.0	134.0	14.0	107	212	-15	0.882	Nil	0.023
2. E_6	61.0	74	G_5	333.2	26	128.6	5.2	1.0	138.0	14.5	106	220	-8	0.877	Nil	0.018
3. E_4	65.0	80	G_5	333.2	20	117.8	5.2	1.0	130.5	13.5	106	218	-6	0.864	Nil	0.011
4. E_7	69.0	76	G_5	333.2	24	126.5	5.2	1.0	137.0	14.0	104	220	-6	0.876	Nil	0.022
5. E_9	88.0	77	G_5	333.2	23	148.6	5.2	1.0	161.5	18.5	118	225	-7	0.884	Nil	0.020

4.5.2 Gear Oils

The five samples of gear oils were prepared and characterized for various properties such as viscosity at 40°C and 100°C, viscosity index, flash point, pour point, inorganic and total acidity and ash content which are depicted in Table 4.31. The grade of the oil after blending of the additives, multipurpose extreme pressure additive for automotive and industrial gear oils (zincdithiophosphate) has also been shown in the Table. All the samples of finished oils prepared from different base stocks passed the corrosion strip test. To make the gear oil of SAE grade 90, the base stocks prepared from G_1, G_2 and G_3, having viscosities of 158.0, 205.0 and 232.6 at 40°C, respectively were considered suitable as the viscosities of these base stocks were appropriate to prepare SAE 90 grade of gear oil.

The five gear oil SAE 90 grade prepared from different base stocks were having variation in their characteristics as shown in Table 4.31 but all these values were failing within the stipulated limits for SAE 90 grade. The viscosity at 40°C and 100°C was increased slightly after blending of additive and varied from 160.2 to 233.8 cst and from 15.5 to 22.0 cst, respectively; the viscosity index for these finished oils varied from 103 to 112. The flash point was in the range of 225°C to 233°C and the pour point varied between -8°C to -11°C. As the finished oil contained additives the ash content increased and was observed to be closer to .01 % which is insignificant. Total acidity was in the range of 0.018 to 0.026 mg KOH /g of oil whereas the inorganic acidity was nil for all the finished oils. Therefore, the oils thus prepared met the quality requirement of SAE 90 grade; however, pour point was higher than the stipulated limit.

To make the gear oil of SAE 140 grade, the base stock prepared from G_4 and G_5 having viscosity of 277.6 and 333.2 cst at 40 was considered suitable as viscosities were appropriate for preparing for preparing SAE 140 grade of gear oil. The finished gear oil SAE 140 grade prepared from two different base stocks were having variation in their characteristics as shown in Table 4.31 but all these values were failing within the stipulated limits for SAE 140 grade. The viscosities increased slightly after blending of additive and were 278.8, 334.2 cst and 28.5, 33.5 cst at 40°C and 100°C respectively; the viscosity index for these finished oils were varied from 122 to 120. The flash point for these oils were in the range of 235°C to 239°C and the pour point varied between -7°C to -6°C. As the finished oil contained additives the ash content increased but the increase was insignificant in both the cases. Total acidity was in the range of 0.021 to 0.023 mg KOH /g of oil whereas the inorganic acidity was nil for all the finished oils. Saponification values for the oils prepared were 0.8 and 0.6 mg KOH/g of oil.

Table 4.31 Characteristics of Finished Gear Oils

Base Stocks from oil	Viscosity of Base Stock at 40°C(cst)	Zincdithiophosphate (%)	Viscosity of Finished Oil (cst)		Viscosity Index	Flash Point (°C)	Pour Point (°C)	Ash Content (%)	Saponification Value (mg KOH/g of oil)	Acidity (mg KOH/g of Oil)	
			At 40°C	At 100°C						Inorganic	Total
1. G_1	158.0	2.75	160.2	15.5	103	225	-8	0.010	0.7	Nil	0.026
2. G_2	205.0	2.75	206.6	19.0	107	228	-10	0.010	0.7	Nil	0.024
3. G_3	232.6	2.75	233.8	22.0	112	233	-11	0.010	0.9	Nil	0.018
4. G_4	277.6	2.75	278.8	28.5	122	235	-7	0.010	0.8	Nil	0.021
5. G_5	333.2	2.75	334.2	33.5	120	239	-6	0.010	0.6	Nil	0.023

4.5.3 Compressor Oils

The three samples of compressor oils were prepared and characterized for various properties such as viscosity at 40°C, viscosity index, flash point, pour point, inorganic and total acidity and ash content which are depicted in Table 4.32. The grade of the oil after blending of the additives, i.e. antifoam agent (silicon oil) and Molybdenum disulfide has also been shown in the Table. All the samples of finished oils prepared from different base stocks passed the corrosion strip test. To make the Compressor oil of grade B, the base stocks prepared from C_1 having viscosities of 33.0, 34.0 cst at 40°C, were considered suitable as the viscosities of these base stocks were appropriate to prepare B grade of Compressor oil. A fixed percent of silicon oil and Molybdenum disulfide has been added to upgrade the quality of oil in terms of rust prevention, oxidation inhibition, foam inhibition, etc. The finished Compressor oil of B grade prepared from different base stocks were although having little variation in their characteristics as shown in Table 4.32 but all these were falling within the stipulated limits for compressor oil under this grade.

The viscosity at 40°C increased slightly after blending of additive and varied and was 35.0 and 35.5 cst for finished oils prepared from two different base stocks of C_1. The colour of the finished oils was +2.0 and +1.0 ASTM units. The flash point was in the range of 164°C to 165°C and the pour point -31°C. Due to the presence of additives the ash content increased and was 0.005 % of finished oils. Total acidity was 0.024 to 0.026 mg KOH /g of oil whereas the inorganic acidity was nil for all the finished oils. Therefore, the oils thus prepared met the quality requirement of B grade compressor oil. To make the compressor oil of C grade, the two different base stock prepared from C_2 having viscosity of 42.0 and 44.5 cst at 40°C, were considered suitable as viscosities of

these base stocks were appropriate to prepare C grade of compressor oil. A fixed percent of silicon oil and Molybdenum disulfide has been added to upgrade the quality of oils.

The finished Compressor oils of C grade prepared from different base stocks were although having little variation in their characteristics as shown in Table 4.32 but all these values were failing within the stipulated limits for compressor oil of C grade. The viscosity at 40°C increased slightly after blending of additives and was 43.5 and 45.5 cst for finished oils prepared from two different base stocks of C_2.The colour of the finished oils was + 2.0 and + 1.0 ASTM units. The flash point was 169°C and pour point - 28°C. Due to the presence of additives the ash content increased but was within the limits prescribed for finished oils. Total acidity for the two oils was 0.022 and 0.025 mg KOH/g of oil whereas the inorganic acidity was nil. Therefore, the oils thus prepared met the quality requirement of C grade Compressor oil.

To make the Compressor oil of D grade, the base stocks prepared from C_3 having viscosity of 63.5 cst at 40°C, was considered suitable as the its viscosity was appropriate to preparing D grade of Compressor oil. A fixed percent of silicon oil and Molybdenum disulfide has been added to upgrade the quality of oils.

The finished Compressor oils of D grade prepared from different base stocks of C_3 oil was characterized and the properties are shown in Table 4.32. The viscosity at 40°C increased slightly after blending of additives and was 65.0 cst. The colour of the finished oils was + 1.0 .The flash point was 174°C and pour point - 27°C. Due to the presence of additives the ash content increased but was within the limits prescribed for finished oils. Total acidity was 0.028 mg

KOH/g of oil whereas the inorganic acidity was nil. Therefore, the oils thus prepared met the quality requirement of D grade Compressor oil.

Table 4.32 Characteristics of Finished Compressor Oils

Base Stocks from oil	Viscosity of Base Stock at 40°C (cst)	Additives (%)		Viscosity of Finished Oil at 40°C (cst)	Colour	Flash Point (°C)	Pour Point (°C)	Ash Content (%)	Acidity (mg KOH/g of Oil)	
		Antifoam Silicon Oil	Molybden -um disulfide						Inorganic	Total
1. C_1	33.0	2.0	4.0	35.0	+2.0	164	-31	0.005	Nil	0.024
2. C_1	34.0	2.0	4.0	35.5	+1.0	165	-31	0.005	Nil	0.026
3. C_2	42.0	2.0	4.0	43.5	+2.0	169	-28	0.005	Nil	0.022
4. C_2	44.5	2.0	4.0	45.5	+1.0	169	-28	0.005	Nil	0.025
5. C_3	63.5	2.0	4.0	65.0	+1.0	174	-27	0.005	Nil	0.028

4.5.4 Hydraulic oils

The five samples of used hydraulic oils were prepared and characterized for various properties such as viscosity at 40°C, viscosity index, flash point, pour point, inorganic acidity, total acidity and ash content which are depicted in Table 4.33. A certain amount of Molybdenum disulfide has been added to upgrade the quality of hydraulic oil in terms of oxidation stability, rust protection, antiwear and foam inhibition. The base stock prepared from H_1 having viscosity of 47.5 cst at 40°C was considered suitable to make the

hydraulic oil of grade VG 46 as the viscosity of this base stock was appropriate for this grade of hydraulic oil. Various properties of the finished hydraulic oil are depicted in Table 4.33. The viscosity at 40°C increased slightly after blending of additive and was 48.0 cst, the viscosity index was 98. There was hardly any change in flash point and pour point after blending of additive. The flash point was 197°C and pour point - 8°C. The ash content increased after blending but increase was negligible. Therefore, the oils thus prepared met the quality requirement of VG 46 grade hydraulic oil. The base stock prepared from H_2 having viscosity of 72.5 cst at 40°C was considered suitable to make the hydraulic oil of grade VG 68 as the viscosity of this base stock was appropriate for this grade of hydraulic oil. Various properties of the finished hydraulic oil are depicted in Table 4.33. The viscosity at 40°C increased slightly after blending of additive and was 73.5 cst, the viscosity index was 97. There was very little change in flash point and no change in pour point after blending of additive. Due to the presence of additives the ash content increased after blending but increase was negligible. The flash point was 210°C and pour point - 5°C. Total acidity was reduced which may be due to the alkaline nature of additive and was 0.026 mg KOH/g of oil whereas the inorganic acidity was nil. Therefore, the oils thus prepared met the quality requirement of VG 68 grade hydraulic oil.

The base stock prepared from H_3 having viscosity of 124.0 cst at 40°C was considered suitable to make the hydraulic oil of grade 121 as the viscosity of was appropriate for 121 grade of hydraulic oil. Various properties of the finished hydraulic oil are depicted in Table 4.33. The viscosity at 40°C increased slightly after blending of additive and was 122.8 cst, after blending of additive which may perhaps be due to the very low viscosity of additives; the

viscosity index was 98. The flash point was 210°C and pour point - 5°C which indicate very little change in flash point and no change in pour point. Due to the presence of additives the ash content increased after blending but increase was negligible. Total acidity was reduced which may be due to the alkaline nature of additive and was 0.025 mg KOH/g of oil whereas the inorganic acidity was nil. Therefore, the oils thus prepared met the quality requirement of 121 grade hydraulic oil. The base stock prepared from H_4 having viscosity of 225.8 cst at 40°C was considered suitable to make the hydraulic oil of grade 220 as its viscosity of was appropriate for preparing this of grade of hydraulic oil. Various properties of the finished hydraulic oil are depicted in Table 4.33. The viscosity at 40°C decreased was 122.8 cst, after blending of additive which may perhaps be due to the very low viscosity of additives; the viscosity index was 94. The flash point was 227°C and pour point - 3°C which indicate very little change in flash point and no change in pour point. Due to the presence of additives the ash content increased after blending but increase was negligible. Total acidity was reduced which may be due to the alkaline nature of additive and was 0.022 mg KOH/g of oil whereas the inorganic acidity was nil.

The base stock prepared from H_5 having viscosity of 335.2 cst at 40°C was considered suitable to make the hydraulic oil of grade 320 as its viscosity of was appropriate for preparing of hydraulic oil. Various properties of the finished hydraulic oil are depicted in Table 4.33. The viscosity at 40°C decreased slightly was 333.8 cst, after blending of additive which may perhaps be due to the very low viscosity of additives; the viscosity index was 92. The flash point was 230°C and pour point - 5°C which indicate very little change in flash point and no change in pour point. Due to the presence of additives the ash content increased after blending but increase was negligible. Total acidity

was reduced which may be due to the alkaline nature of additive and was 0.024 mg KOH/g of oil whereas the inorganic acidity was nil.

Table 4.33 Characteristics of Finished Hydraulic Oils

Base Stocks from oil	Viscosity of Base Stock at 40°C (cst)	Molybdenum disulfide Additive (%)	Viscosity of Finished Oil at 40°C (cst)	Viscosity Index	Flash Point (°C)	Pour Point (°C)	Ash Content (%)	Acidity (mg KOH/g of Oil)	
								Inorganic	Total
1. H_1	47.5	1.1	48.0	98	197	-8	0.003	Nil	0.023
2. H_2	72.5	1.1	73.5	97	210	-5	0.003	Nil	0.026
3. H_3	124.0	1.1	122.8	98	220	-5	0.003	Nil	0.025
4. H_4	225.8	1.1	224.4	94	227	-3	0.004	Nil	0.022
5. H_5	335.0	1.1	333.8	92	230	-5	0.004	Nil	0.024

CHAPTER - 5

CONCLUSION AND RECOMMENDATION

The objectives of this experimental research have been achieved to fairly good extent. Some important conclusions have been drawn from the critical analysis of the results obtained for various used lubricating oils.

5.1 USED ENGINE OILS

The experimental study of used engine oil has provided the following inferences.

i) The colour of the used oils was improved from (+2.5 to +5.5) on refining due to the removal of carbonaceous matter, oxidative products and extraneous impurities.

ii) The viscosity of the used oils in increased on refining from 39.0 to 84.5 cst due to the removal of light ends present in used oils.

iii) The flash point of the used oils increased from 140 to 215°C on their refining. It is due to the removal of light ends having lower flash point.

iv) Decrease in ash content from 2.65 to 0.007 % shows the proper refining as the additives and carbon particles present in used oils were removed in refining process.

v) After blending of additives (Molybdenum disulfide and Polyisobutylene) in base stocks, the viscosity and ash content were increased from 10.5 to 14.0°C and from 0.863 to 0.872% respectively. The flash point and pour point were more or less same for finished oils. Total acidity was reduced from 0.026 to 0.018 mg KOH/g of oil which may be due to the alkaline nature of additives.

5.2 USED GEAR OILS

The pertinent findings from the study of used gear oils are as follows:

i) The colour of the used gear oils improved from (+2.5 to +5.0) on refining due to the removal of carbonaceous matter, oxidative products and extraneous impurities.

ii) The viscosity of the used gear oils increased from on refining from 154.4 to 334.0 cst due to the removal of polymerized oils present in used oils and lesser removal of light ends in comparison to that in used engine oils.

iii) There was little increase from 220 to 235°C in flash point of used gear oils on refining which was due to the removal of lower fractions although lesser in comparison to that in used engine oils.

iv) Decrease in ash content from 0.5 to 0.004% shows the proper refining of used gear oils as the additives and carbon particles present in used gear oils were removed in refining process.

v) After blending of additive (Zincdithiophosphate) in base stocks the viscosity and ash content were increased. While the flash point and pour point remained almost unchanged. The Total acidity was

reduced from 0.026 to 0.018 mg KOH/g of oil which may be due to the alkaline nature of additive.

5.3 USED COMPRESSOR OILS

As far as, used compressor oils are concerned, the following inferences were obtained:

i) The colour of the used compressor oils was improved (+1.0 to +3.0) similar to used engine and gear oils.

ii) The viscosity of the used compressor oils increased from on refining from 30.0 to 65.0 cst also like engine and gear oils but to extent as compared to used engine oils.

iii) The little increase in flash point from 164 to 174°C of used compressor oils on refining was observed which is due to the removal of low quantity of lower fraction.

iv) Decrease in ash content from 0.02 to 0.002 % shows the proper refining of used compressor oils as additives and carbon particles present in used compressor oils were removed in refining process.

v) After blending of additives in base stocks the viscosity and ash content were increased. The flash point and pour point were more or less same for finished oils. Total acidity was reduced from 0.028 to 0.022 mg KOH/g which may be due to the alkaline nature of additive.

5.4 USED HYDRAULIC OILS

Some samples of used hydraulic oils were also studied. The following important conclusions are as follows:

i) The colour of the used hydraulic oils was improved on refining from (+1.5 to +2.5).

ii) The viscosity of the used hydraulic oils was increased on refining from 45.5 to 336.0 cst.

iii) The little increase in flash point of used hydraulic oils on refining was observed from 195 to 229°C.

iv) Decrease in ash content from 0.7 to 0.003 % shows the proper refining of used hydraulic oils as additives and carbon particles present in used hydraulic oils were removed in refining process.

v) After blending of additive in base stocks the viscosity of finished oils from H_3, H_4 and H_5 was decreased this may be due to the low viscosity of additive. The flash point and pour point were more or less same for finished oils. Total acidity was reduced which may be due to the alkaline nature of additive.

RECOMMENDATION

The following recommendation based upon the conclusions obtained from this experimental study, can be made for further investigations;

1. More properties (like oxidation stability, evaporation loss etc.) and parameters (corrosion and engine wear) should be investigated besides the viscosity, colour, ash content, flash point and total acidity of used lubricating oils.

2. More wide range of lubricants (low, medium and high speed diesel engine oils) should be tested to make the study more acceptable.

3. Due to rapid industrialization worldwide, the new energy options are need of the hour. Hence, scaling up of this study to pilot plant and further commercial-ization of the project will be right and pertinent solution to the decreasing petrol -eum reserves and degrading environment from health view point as well.

BIBLIOGRAPHY

1. Basel Convention Technical guidelines on used oil or other re-uses of previously used oil, International Conference - Geneva, 1995.

2. Michel Bourgois, Guidelines on Used oil Management International Experiences and approach for Colombia, 1995.

3. http: // www.recycleoil.org/ usedoilflow.html

4. Recycling oil saves the environment, Material safety data sheets, http://www.rose foundation.org.za/html

5. F. J. Ogbonna and E. O. Samuel, Comparative study of different media in reduction of pollutants in used lubricating oil, Nigeria- a case study, Asian Research Publishing Network, Journal of Engineering and Applied Sciences, Vol. 4, No. 8, 2009.

6. A. U. Valiante, A critical review of the used oil management association (UO-MA) program review, 2005.

7. N. N. Li, Separation of wax and oil by centrifugation, Ind. Eng. Chem. Process, 8 (1), pp. 89-92, 1969.

8. M.A. Scapin, C. Duarte, M.H.O. Sampa and I.M. Sato, Recycling of the used automotive lubricating oil by ionizing radiation process, Science-direct, Radiation Physics and Chemistry, 76(4), pp. 1889-1902, 2007.

9. Jesusa Rincon, Pablo Caizares, and Mara Teresa Garca, Waste oil recycling using mixtures of polar solvents, Ind. Eng. Chem. Res., 44 (20), pp.7854-7859, 2005.

10. Bob Boughton, and Arpad Horvath, Environmental assessment of used oil management methods, Environmental Science & Technology, 38 (2), pp.1353-1358, 2004.

11. William P. Hettinger, Reclaiming lube oil in MRS unit, U. S. Patent, 4, 551, 234, 1985.

12. Jesusa Rincon, Pablo Canizares and Marıia Teresa Garcia, Improvement of the waste oil vacuum distillation recycling by continuous extraction with dense propane, Ind. Eng. Chem. Res., 46 (1), pp. 266-272, 2007.

13. Seung-Soo Kim, Byung Hee Chun and Sung Hyun Kim, Non-isothermal pyrolysis of waste automobile lubricating oil in a stirred batch reactor, Chemical Engineering Resource, 93, pp. 225-231, 2003.

14. R. E. Linnard and L. M. Henton, Re-refine waste oil with PROP, Hydrocarbon Processing, Vol.58, No. 9, pp. 148-15, 1979.

15. E. A. Malick, What is the real value of re-refining? Hydrocarbon Processing, Vol. 58, No.9, pp.11-12, 1979.

16. S.Whisman, E. Marvinl, W.R. James, J.W. Goetzinger, F.C. Brinkman and W. Dennil, Re-refining makes quality oils, Hydrocarbon Processing, Vol. 58, No. 9, pp. 141-145, 1979.

17. T.N. Kalnes, Used oil re-refining process (less costly), Hydrocarbon Processing, Vol. 69, No. 9, pp. 21-22, 1990.

18. C. Selby and W. Theodor, Marketed engine oils: a comparative analysis of products made from refined and re-refined base stocks, Am. Chem. Society, Vol. 37, No. 4, pp. 267- 276, 1992.

19. P.R. Crowley, Re-refining used lube oil, U.S. Patent, 4,169,044, 1979.

20. E.W.Wood and K.Donald, Reclaiming used lubricating oil, U.S. Patent, 4,381,992, 1983.

21. M.M.Johnson, Reclaiming used motor oil, U.S. Patent, 3,930,988, 1976.

22. E.Eckhard and H.R. Kobel, Process for reclaiming used hydrocarbon oils, U.S. Patent, 4,097,369, 1978.

23. M.L.Whisman and J.W. Reynolds, Process for preparing lubricating oil from used waste lubricating oil, U.S. Patent, 4,073,719, 1978.

24. H.B.Shoemaker and I.Hammond, Method of treating and reclaiming lubricating oils, U.S.Patent, 2,070626, 1937.

25. Pierre Grandvallet and A.P. Hagan, Upgrading of pre-processed used oils, U.S. Patent, 7,261808, 2007.

26. C.R.Mellen, Process for contaminated oil reclamation, U.S. Patent, 5,556,548, 1996.

27. C.T. Mead and H.J.Wright, Process for reclaiming used lubricating oil, U.S.Patent, 4,490,245, 1984.

28. L.C.Fletcher and J.H.Beard, Method of re-refining used lubricating oil, U.S. Patent, 4,342, 645, 1982.

29. Alessandra Borin and R.J. Poppi, Multivariate quality control of lubricating oils using fourier transform infrared spectroscopy, Journal of Brazil Chemical Society , Vol.15, No.4, pp. 570-576, 2004.

30. A.Agoston, C.Otsch and B.Jakoby, Viscosity sensors for engine oil condition monitoring - application and interpretation of results, Science- direct, 121, pp. 327-332, 2005.

31. C. Laird Fletcher and H. Richard, Solvent extraction process for re-refining used lubricating oil, U.S. Patent, 4,399025, 1983.

32. Carlos G. Fuertes and Miguel Balada Subirats, Used mineral motor oil ecological recycling procedure, U.S. Patent, 5,639,383, 1997.

33. Erich-Klaus Martin and Adekunle Onabajo, Method of cleaning and regenerating used oils, U.S.Patent, 5,141,628, 1992.

34. Quang Dang and Francois Audibert, Process for regenerating used lubricating oils, 3,773,658, 1973.

35. J.A. Aramburu, Process for re-refining used oils by solvents extraction, U.S. Patent, 7,226,533, 2007.

36. Jesusa Rincon, Pablo Caizares and Mara Teresa Garca, Regeneration of used lubricant oil by propane extraction, Ind. Eng. Chem. Res., 42(20), pp. 4867- 4873, 2003.

37. A.Krzymien and P.Krzymien, Selection of lubricating oil aimed at reduction of IC-Engine friction losses, Journal of KONES Internal Combustion Engines, Vol.10, No.3, 2003.

38. M.Alves dos Reis and M.Silva Jeronimo, Waste lubricating oil re-refining by extraction by extraction - flocculation.1. A Scientific basis to design efficient solvents, Ind. Eng. Chem. Res., 27(7), pp. 1222-28, 1988.

39. G.Pignalosa, M.Knochem and N.Cabrera, Determination of zinc based additives in lubricating oils by flow- injection analysis with flame - AAS detection exploiting injection with a computer - controlled syringe, Journal of Automated Methods and Management in Chemistry, No.1, pp.1-7, 2005.

40. Harry levin and Charles C. Towe, Determination of un-dissolved sludge in used oils, Industrial and Engineering Chemistry, Vol. 11, No. 4, pp.181-183, 1939.

41. M. Alves dos Reis, Waste lubricating oil re-refining by extraction flocculation.3.A pilot plant study, Ind. Eng. Chem. Res., 30 (11), pp. 2249-2456, 1991.

42. Mohammad Shakirullah, Imtiaz Ahmad, Mohammad Saeed, Mohammad Arsala Khan, Habib-ur-Rehman, Mohammad Ishaq and Amjad Ali Shah, Environmentally friendly recovery and characterization of oil from used engine lubricants, Journal of the Chinese Chemical Society, 53, pp. 335-342 ,2006.

43. Heitor Breno, Pereira Ferreira, Paulo Jorge and Sanches Barbeira, Energy Fuels, Voltammetric determination of zinc in lubricating oils, pp. 1-7, 2009.

44. G. Mazzanti and H. frampon, Re-refining adds furfural stage, Hydrocarbon Processing, Vol. 55, No.8, pp. 123-126, 1976.

45. W.Dennis, Brinkman and John Dickson, Contaminants in used lubricating oils and their fate during distillation hydro-treatment re-refining, Environmental Science & Technology, 29 (1), pp. 81-86, 1995.

46. Didier Gourgouillon, Luc Schrive and Stphane Sarrade, An environmentally friendly process for the regeneration of used oils, Environmental Science and Technology, 34 (6), pp. 346-353, 2000.

47. Jesusa Rincon, Pablo Caizares and Mara Teresa Garca, Regeneration of used lubricant oil by polar solvent extraction, Ind. Eng. Chem. Res.,44 (12), pp. 4337-4379, 2005.

48. J. P. Martins, The extraction-flocculation re-refining lubricating oil processes using ternary organic solvents, Ind. Eng. Chem. Res., 36 (9), pp. 3854-3858, 1997.

49. Jelena Lukic, Aleksandar Orlovi, Michael Spiteller, Jovan Jovanovic and Dejan Skala, Re-refining of waste mineral insulating oil by extraction with N-methyl-2-pyrrolidone, Science-direct, Separation and Purification Technology 51, pp. 150-156, 2006.

50. Ricardo Queiroz Aucelio and Adilson Jose Curtius, The Analyst, Comparative study of electrothermal atomic absorption spectrometric methods for the determination of silver in used lubricating oils, 125, pp. 1673-1679, 2000.

51. J. Bishop and D. Arlidge, Evaporator: use in re-refining, Hydrocarbon Processing, Vol.58, No. 7, pp. 131-136, 1979.

52. S. R. Bethea, D. S. Bosniack and E. L. Mohundro, To hydro-treat Waste lube oil, Hydrocarbon Processing, Vol. 52, No. 9, pp. 134-136, 1973.

53. M. J. Chaddha, G. K. Ghosal and K. V. Koranne, Reclamation of used engine lubricating oil - recent trends, Institution of Engineers (India) Journal-CH, Vol. 68, No.4 , pp. 329-334, 1987.

54. Elena Dominguez-Rosado and John Pichtel, Phytoremediation of soil contaminated with used motor oil: II. Greenhouse studies, Environmental Engineering Science, Vol. 21, No.2, pp.169-180, 2004.

55. Nabil M. Abdel-Jabbar, Essam A.H. Al Zubaidy and Mehrab Mehrvar, Waste lubricating oil treatment by adsorption process using different adsorbents, World Academy of Science, Engineering and Technology, 62, 2010.

56. S. Rawat and Guru Prasad, Determination of Trace Solvent in Waxes and Lubricating Oils, American Chemical Society, 53, 1145-1146, 1981

57. Harold Beuther, R. E. Donaldson and A. M. Henke, Hydro-treating to produce high viscosity index lubricating oils, Ind. Eng. Chem. Res., 3 (3), pp.174-180, 1964.

58. Mithilesh Kumar Jha, Re-refining of used lube oils: Indian Chem. Engr., Vol.47, No. 3, 2005.

59. Manzoor A. Khawaja and Mahmoud M. Aban, Characteristics of used lubricating oils, their environmental impact and survey of disposal methods, Environmental Management and Health, 7(1), pp. 23-32 ,1996.

60. Ranvir Singh, Manoj Srivastava, Manoj Kumar, U.C. Agrawal and M.O.Garg, An extraction- adsorption combo-process for re-refining of used oil, Petro-Tech, pp. 1-7, 2009.

61. H. Bridjanian and M. Sattarin, Modern Recovery methods in used oil re-refining, Petroleum & Coal, 48 (1), pp. 40-43, 2006.

62. A. James Spearot, Viscosity of severely oxidized engine oil, Ind. Eng. Chem. Prod. Res., 13 (4), pp. 259-267, 1974.

63. Farshid Owrang, Hakan Mattsson, Jim Olsson and Jorgen Pedersen, Investigation of oxidation of a mineral and a synthetic engine oil, Science-direct, Elsevier, Thermochimica Acta, 413, pp. 241-248, 2004.

64. A. Kamal and F. Khan, Effect of Extraction and Adsorption on Re-refining of used lubricating oil, Oil & Gas Science and Technology, pp.1-7, 2009.

65. S. O. Ogbeide, An Investigation to the Recycling of Spent Engine Oil, Journal of Engineering Science and Technology Review, 3 (1), pp.32-35, 2010.

Appendix - Experimental Data

Table 4.34 The effect of solvent to oil ratio on the extraction performance measured by the percent oil losses using of 1-butanol at various temperatures

S to O Ratio	%OL 20 °C	S to O Ratio	%OL 30 °C	S to O Ratio	%OL 40 °C	S to O Ratio	%OL 48 °C	S to O Ratio	%OL 50 °C	S to O Ratio	%OL 52 °C
1. 0.8	17.5	1.6	16.8	1.7	15.7	1.6	15.5	1.5	14.4	1.6	13.9
2. 1.3	17.4	2.1	16.3	2.6	15.0	2.4	14.7	2.4	13.6	2.1	12.3
3. 1.6	17.0	2.5	16.0	3.7	14.5	3.4	14.2	3.1	13.1	2.4	11.6
4. 2.1	16.7	3.7	15.4	4.5	14.1	4.1	13.8	3.5	12.4	3.5	11.1
5. 2.6	16.2	4.6	15.0	5.1	13.5	4.5	13.1	4.0	11.5	4.6	10.1
6. 3.1	16.0	5.2	14.6	6.7	13.1	5.0	12.8	5.0	10.5	5.4	9.4
7. 3.5	15.7	5.5	14.5	7.1	13.1	5.5	12.8	5.8	10.2	6.8	9.4
8. 4.6	15.5	6.1	14.5	7.9	13.1	6.3	12.8	6.9	10.2	7.1	9.4
9. 5.5	15.4	6.5	14.5	8.1	13.1	7.2	12.8	7.2	10.2	7.5	9.4
10. 6.6	15.4	7.0	14.5	8.6	13.1	8.1	12.8	8.5	10.2	8.5	9.4
11. 7.8	15.4	8.1	14.5	9.1	13.1	9.2	12.8	9.0	10.2	9.1	9.4

(S to O Ratio = Solvent to oil ratio, % OL = Percent oil losses)

Table 4.35 The effect of solvent to oil ratio on the extraction performance measured by the percent oil losses using of 2-propanol at various temperatures

S to O Ratio	%OL 20 °C	S to O Ratio	%OL 30 °C	S to O Ratio	%OL 40 °C	S to O Ratio	%OL 48 °C	S to O Ratio	%OL 50 °C	S to O Ratio	%OL 52 °C
1. 0.9	16.5	1.3	17.2	1.5	15.5	1.5	14.9	1.5	14.5	1.4	13.8
2. 1.2	15.7	1.9	14.3	2.5	12.1	2.5	12.1	2	10.2	1.9	9.6
3. 1.5	15.1	2.5	13.8	3.7	11.8	3.0	11.5	2.5	9.6	2.4	9.1
4. 2.0	14.7	3.5	13.4	4.5	11.4	3.5	10.6	3.5	9.6	3.5	8.7
5. 2.5	14.4	4.6	12.7	5.0	11.1	4.5	10.2	4.0	9.1	4.1	8.1
6. 3.0	13.9	5.0	12.7	6.4	11.1	5.0	9.8	5.0	8.5	5.4	7.8
7. 3.5	13.9	5.5	12.7	6.9	11.1	5.5	9.8	5.8	8.5	6.4	7.5
8. 4.5	13.9	6.0	12.7	7.3	11.1	6.0	9.8	6.9	8.0	6.9	7.5
9. 5.5	13.9	6.5	12.7	7.9	11.1	7.2	9.8	7.7	8.0	7.5	7.5
10. 6.5	13.9	7.0	12.7	8.2	11.1	8.0	9.8	8.3	8.0	7.9	7.5
11. 7.5	13.9	7.5	12.7	8.9	11.1	8.5	9.8	8.8	8.0	8.5	7.5

Table 4.36 The effect of solvent to oil ratio on the extraction performance measured by the percent oil losses using of Methyl Ethyl Ketone at various temperatures

S to O Ratio	%OL 20 °C	S to O Ratio	%OL 30 °C	S to O Ratio	%OL 40 °C	S to O Ratio	%OL 48 °C	S to O Ratio	%OL 50 °C	S to O Ratio	%OL 52 °C
1. 2.5	10.3	2.6	10.1	2.5	9.7	2.7	9.5	2.6	9.1	2.8	8.8
2. 3.0	10.1	3.2	9.7	3.4	9.3	3.4	9.2	3.5	8.6	3.5	8.5
3. 4.5	9.6	3.8	9.4	3.8	9.1	3.8	8.7	4.1	8.2	4.6	8.1
4. 5.0	9.4	4.5	9.1	4.5	8.7	4.4	8.5	4.9	7.8	5.3	7.4
5. 5.5	9.2	5.1	8.6	5.0	8.5	4.8	8.1	5.5	7.5	6.1	7.2
6. 6.0	8.6	6.3	8.1	6.5	8.1	5.2	7.5	6.0	7.3	6.9	6.8
7. 6.5	8.3	7.6	8.1	6.9	7.8	6.8	7.5	6.5	7.3	7.5	6.8
8. 7.5	8.3	7.9	8.1	7.5	7.8	7.8	7.5	7.6	7.3	8.7	6.8
9. 8.1	8.3	8.2	8.1	8.3	7.8	8.9	7.5	8.9	7.3	9.1	6.8
10. 8.7	8.3	8.7	8.1	9.3	7.8	9.2	7.5	9.5	7.3	9.6	6.8
11. 9.0	8.3	9.3	8.1	10.1	7.8	10.2	7.5	10.2	7.3	10.4	6.8

Table 4.37 The effect of solvent to oil ratio on the extraction performance measured by the percent oil losses using of Methyl Iso Butyl Ketone at various temperatures

S to O Ratio	%OL 20 °C	S to O Ratio	%OL 30 °C	S to O Ratio	%OL 40 °C	S to O Ratio	%OL 48 °C	S to O Ratio	%OL 50 °C	S to O Ratio	%OL 52 °C
1. 2.5	10.9	2.6	10.8	2.5	10.6	2.7	10.3	2.6	9.7	2.8	9.5
2. 3.0	10.5	3.2	10.5	3.4	10.2	3.4	9.7	3.5	9.5	3.5	8.8
3. 4.5	10.1	3.8	9.4	3.8	9.8	3.8	9.5	4.1	9.1	4.6	8.5
4. 5.0	9.7	4.5	9.6	4.5	9.3	4.4	9.3	4.9	8.6	5.3	8.1
5. 5.5	9.4	5.1	9.3	5.0	9.1	4.8	8.8	5.5	8.1	6.1	7.6
6. 6.0	9.2	6.3	8.9	6.5	8.7	5.2	8.5	6.0	7.8	6.9	7.3
7. 6.5	9.2	7.6	8.9	6.9	8.7	6.8	8.5	6.5	7.5	7.5	7.1
8. 7.5	9.2	7.9	8.9	7.5	8.7	7.8	8.5	7.6	7.5	8.7	7.1
9. 8.1	9.2	8.2	8.9	8.3	8.7	8.9	8.5	8.9	7.5	9.1	7.1
10. 8.7	9.2	8.7	8.9	9.3	8.7	9.2	8.5	9.5	7.5	9.6	7.1
11. 9.0	9.2	9.3	8.9	10.1	8.7	10.2	8.5	10.2	7.5	10.4	7.1

Table 4.38 Percent oil losses using solvents at 20°C

S to O Ratio	%OL 1-butanol	S to O Ratio	%OL 2-propanol	S to O Ratio	%OL for MIBK	S to O Ratio	%OL for MEK
1. 0.8	17.5	0.9	16.5	2.5	10.9	2.5	10.3
2. 1.3	17.4	1.2	15.7	3.0	10.5	3.0	10.1
3. 1.6	17.0	1.5	15.1	4.5	10.1	4.5	9.6
4. 2.1	16.5	2.0	14.7	5.0	9.7	5.0	9.4
5. 2.6	16.0	2.5	14.4	5.5	9.4	5.5	9.2
6. 3.1	15.8	3.0	13.9	6.0	9.2	6.0	8.6
7. 3.5	15.4	3.5	13.9	6.5	9.2	6.5	8.3
8. 4.6	15.4	4.5	13.9	7.5	9.2	7.5	8.3
9. 5.5	15.4	5.5	13.9	8.1	9.2	8.1	8.3
10. 6.6	15.4	6.5	13.9	8.7	9.2	8.7	8.3
11. 7.8	15.4	7.5	13.9	9.0	9.2	9.0	8.3

Table 4.39 Percent oil losses using solvents at 30°C

S to O Ratio	%OL 1-butanol	S to O Ratio	%OL 2-propanol	S to O Ratio	%OL for MIBK	S to O Ratio	%OL for MEK
1. 1.6	16.8	1.3	17.2	2.6	10.8	2.6	10.1
2. 2.1	16.5	1.9	14.3	3.2	10.5	3.2	9.7
3. 2.5	16.2	2.5	13.8	3.8	9.8	3.8	9.4
4. 3.7	15.7	3.5	13.4	4.5	9.6	4.5	9.1
5. 4.6	15.2	4.6	12.7	5.1	9.3	5.1	8.6
6. 5.2	14.6	5.0	12.7	6.3	8.9	6.3	8.1
7. 5.5	14.6	5.5	12.7	7.6	8.9	7.6	8.1
8. 6.1	14.6	6.0	12.7	7.9	8.9	7.9	8.1
9. 6.5	14.6	6.5	12.7	8.2	8.9	8.2	8.1
10. 7.0	14.6	7.0	12.7	8.7	8.9	8.7	8.1
11. 8.1	14.6	7.5	12.7	9.3	8.9	9.3	8.1

(MIBK = Methyl iso butyl ketone, MEK = Methyl ethyl ketone)

Table 4.40 Percent oil losses using solvents at 40°C

S to O Ratio	%OL 1-butanol	S to O Ratio	%OL 2-propanol	S to O Ratio	%OL for MIBK	S to O Ratio	%OL for MEK
1. 1.7	15.7	1.5	15.5	2.5	10.6	2.6	9.7
2. 2.6	15.0	2.5	12.1	3.5	10.2	3.4	9.3
3. 3.7	14.5	3.7	11.8	3.8	9.8	3.8	9.1
4. 4.5	14.1	4.5	11.4	4.5	9.3	4.4	8.7
5. 5.1	13.5	5	11.1	5.1	9.1	5	8.5
6. 6.7	13.1	6.4	11.1	6.5	8.7	6.6	8.1
7. 7.1	13.1	6.9	11.1	7.1	8.7	6.9	7.8
8. 7.9	13.1	7.3	11.1	7.5	8.7	7.6	7.8
9. 8.1	13.1	7.9	11.1	8.4	8.7	8.3	7.8
10. 8.6	13.1	8.2	11.1	9.3	8.7	9.2	7.8
11. 9.1	13.1	8.9	11.1	10.1	8.7	10.2	7.8

Table 4.41 Percent oil losses using solvent at 48°C

S to O Ratio	%OL 1-butanol	S to O Ratio	%OL 2-propanol	S to O Ratio	%OL for MIBK	S to O Ratio	%OL for MEK
1. 1.6	15.5	1.5	14.9	2.6	10.3	2.7	9.5
2. 2.4	14.7	2.5	12.1	3.4	9.7	3.5	9.2
3. 3.4	14.2	3.0	11.5	3.8	9.5	4.0	8.7
4. 4.1	13.8	3.5	10.6	4.4	9.3	4.6	8.5
5. 4.4	13.1	4.5	10.2	4.6	8.8	4.8	8.1
6. 5.0	12.8	5.3	9.8	5.2	8.5	5.7	7.5
7. 5.5	12.8	5.5	9.8	6.7	8.5	6.8	7.5
8. 6.3	12.8	6.0	9.8	7.7	8.5	7.8	7.5
9. 7.1	12.8	7.5	9.8	8.6	8.5	8.9	7.5
10. 8.3	12.8	8.0	9.8	9.1	8.5	9.2	7.5
11. 9.2	12.8	8.5	9.8	10.3	8.5	10.2	7.5

Table 4.42 Percent oil losses using solvents at 50°C

S to O Ratio	%OL 1-butanol	S to O Ratio	%OL 2-propanol	S to O Ratio	%OL for MIBK	S to O Ratio	%OL for MEK
1. 1.4	14.4	1.5	14.5	2.7	9.7	2.6	9.1
2. 2.4	13.6	2	10.2	3.6	9.5	3.4	8.6
3. 3.1	13.1	2.5	9.6	4.2	9.1	4.0	8.2
4. 3.5	12.4	3.5	9.6	4.6	8.6	4.9	7.8
5. 4.2	11.5	4.0	9.1	5.4	8.1	5.5	7.5
6. 5	10.5	5.0	8.6	6.2	7.8	5.9	7.3
7. 5.7	10.2	5.8	8.4	6.4	7.5	6.5	7.3
8. 7.2	10.2	6.9	8.1	7.5	7.5	7.6	7.3
9. 7.8	10.2	7.7	8.1	8.8	7.5	9.1	7.3
10. 8.5	10.2	8.3	8.1	9.4	7.5	9.6	7.3
11. 9.1	10.2	8.8	8.1	10.2	7.5	10.5	7.3

Table 4.43 Percent Oil losses using solvents at 52°C

S to O Ratio	%OL 1-butanol	S to O Ratio	%OL 2-propanol	S to O Ratio	%OL for MIBK	S to O Ratio	%OL for MEK
1. 1.6	13.9	1.4	13.8	2.6	9.5	2.8	8.8
2. 2.1	12.3	1.9	9.6	3.4	8.8	3.5	8.5
3. 2.3	11.6	2.4	9.1	4.5	8.5	4.6	8.1
4. 3.4	11.1	3.5	8.7	5.1	8.1	5.3	7.4
5. 4.6	10.6	4.1	8.1	6.0	7.6	6.4	7.2
6. 5.4	9.4	5.4	7.8	6.7	7.3	7.2	6.8
7. 6.8	9.4	6.4	7.5	7.4	7.1	7.5	6.8
8. 7.1	9.4	6.9	7.5	8.2	7.1	8.7	6.8
9. 7.4	9.4	7.5	7.5	9.0	7.1	9.4	6.8
10. 8.5	9.4	7.9	7.5	9.5	7.1	9.8	6.8
11. 9.1	9.4	8.5	7.5	10.4	7.1	10.6	6.8

Table 4.44 The effect of solvent to oil ratio on the extraction performance measured by percent sludge removal using of 1-butanol at various temperatures

S to O Ratio	%SR 20 °C	S to O Ratio	%SR 30 °C	S to O Ratio	%SR 40 °C	S to O Ratio	%SR 48 °C	S to O Ratio	%SR 50 °C	S to O Ratio	%SR 52 °C
1. 1.5	1.8	1.4	1.6	1.7	1.6	1.6	1.5	1.5	1.5	1.6	1.4
2. 2.3	2.4	2.1	2.1	2.6	3.1	2.4	2.6	2.4	2.3	2.1	1.7
3. 2.5	3.6	2.5	3.2	3.7	3.9	3.4	3.4	3.4	2.9	2.4	1.9
4. 3.7	4.8	3.7	4.6	4.5	4.6	4.1	4.1	3.7	3.1	3.5	2.8
5. 4.6	5.7	4.6	5.2	5.1	5.2	4.5	4.4	4.2	3.6	4.6	3.4
6. 5.3	6.4	5.2	5.6	5.7	5.9	5.0	4.8	5.0	4.1	5.4	3.8
7. 5.7	6.8	5.5	6.2	6.4	6.1	5.5	5.5	5.8	5.1	6.8	4.8
8. 6.6	6.9	6.1	6.7	6.7	6.3	6.3	5.8	6.9	5.3	7.1	4.8
9. 7.3	7.4	6.8	6.9	7.3	6.3	7.2	5.8	7.2	5.3	7.5	4.8
10. 7.7	7.4	7.9	6.9	8.3	6.3	8.1	5.8	8.5	5.3	8.5	4.8
11. 9.5	7.4	9.1	6.9	9.1	6.3	9.2	5.8	9.0	5.3	9.1	4.8

(% SR = Percent sludge removal)

Table 4.45 The effect of solvent to oil ratio on the extraction performance measured by percent sludge removal using of 2-propanol at various temperatures

S to O Ratio	%SR 20 °C	S to O Ratio	%SR 30 °C	S to O Ratio	%SR 40 °C	S to O Ratio	%SR 48 °C	S to O Ratio	%SR 50 °C	S to O Ratio	%SR 52 °C
1. 1.4	1.8	1.3	1.5	1.6	1.5	1.5	1.4	1.4	1.3	1.5	1.3
2. 2.1	2.5	2.1	1.9	2.6	2.9	2.3	2.4	2.4	2.2	2	1.5
3. 2.5	3.4	2.5	3.1	3.7	3.7	3.4	3.3	3.3	2.7	2.2	1.8
4. 3.7	4.5	3.6	4.4	4.4	4.5	4.0	3.9	3.7	2.9	3.5	2.7
5. 4.6	5.4	4.5	5.0	5.0	5.0	4.5	4.2	4.1	3.5	4.5	3.3
6. 5.2	5.8	5.1	5.4	5.6	5.7	5.0	4.7	4.9	4.0	5.4	3.5
7. 5.5	6.5	5.4	6.1	6.3	5.9	5.4	5.3	5.6	4.9	6.8	4.5
8. 6.1	6.7	6.0	6.5	6.7	6.1	6.1	5.5	6.7	5.1	7.0	4.5
9. 6.8	7.1	6.8	6.7	7.2	6.1	7.2	5.5	7.0	5.1	7.3	4.5
10. 7.9	7.1	7.8	6.7	8.1	6.1	7.9	5.5	8.5	5.1	8.2	4.5
11. 9.1	7.1	9.0	6.7	9.1	6.1	9.0	5.5	8.9	5.1	9.0	4.5

Table 4.46 The effect of solvent to oil ratio on the extraction performance measured by percent sludge removal using of methyl ethyl ketone at various temperatures

S to O Ratio	%SR 20 °C	S to O Ratio	%SR 30 °C	S to O Ratio	%SR 40 °C	S to O Ratio	%SR 48 °C	S to O Ratio	%SR 50 °C	S to O Ratio	%SR 52 °C
1. 2.1	1.4	2.3	1.3	2.4	1.3	2.4	1.2	2.4	1.2	2.4	1.1
2. 2.5	1.7	2.7	2.7	3.1	2.2	3.2	2	2.8	1.4	2.8	1.3
3. 3.2	2.9	3.8	3.5	3.8	3.1	3.7	2.5	3.2	1.6	3.2	1.5
4. 3.7	4.3	4.4	4.3	4.2	3.7	4.3	2.8	3.9	2.4	3.9	2.3
5. 4.6	4.8	5.6	4.8	4.9	4.1	4.8	3.3	4.5	3.0	4.5	2.8
6. 5.2	5.2	6.1	5.5	5.8	4.5	5.6	3.8	5.4	3.3	5.4	3.2
7. 6.2	6.0	7.3	5.6	6.7	5.1	6.3	4.7	6.8	4.3	6.8	4.1
8. 7.2	6.3	7.8	5.9	7.4	5.3	7.3	4.9	7.8	4.3	7.8	4.1
9. 8.3	6.5	8.3	5.9	8.5	5.3	8.2	4.9	8.6	4.3	8.6	4.1
10. 9.2	6.5	9.2	5.9	9.1	5.3	9.3	4.9	9.6	4.3	9.6	4.1
11. 10.2	6.5	10.3	5.9	9.9	5.3	9.9	4.9	10.2	4.3	10.2	4.1

Table 4.47 The effect of solvent to oil ratio on the extraction performance measured by the percent sludge removal using of methyl iso butyl ketone at various temperatures

S to O Ratio	%SR 20 °C	S to O Ratio	%SR 30 °C	S to O Ratio	%SR 40 °C	S to O Ratio	%SR 48 °C	S to O Ratio	%SR 50 °C	S to O Ratio	%SR 52 °C
1. 1.9	1.2	2.1	1.2	2.3	1.2	2.2	1.1	2.3	1.1	2.3	1.0
2. 2.4	1.5	2.5	2.5	3.0	2	3.0	1.9	2.5	1.2	2.5	1.1
3. 3	2.6	3.5	3.3	3.5	2.9	3.5	2.3	3.0	1.3	3.0	1.3
4. 3.5	4.1	4.2	4.2	4.0	3.5	4.1	2.5	3.7	2.2	3.7	2.0
5. 4.5	4.5	5.5	4.5	4.7	4.0	4.5	3	4.5	2.9	4.5	2.6
6. 5.1	5.0	6.0	5.2	5.5	4.3	5.5	3.6	5.2	3.0	5.2	2.9
7. 6.0	5.9	7.1	5.3	6.5	5.0	6.1	4.5	6.6	4.1	6.6	3.5
8. 7.1	6.1	7.5	5.7	7.3	5.1	7.2	4.7	7.5	4.1	7.5	3.5
9. 8.1	6.2	8.2	5.7	8.3	5.1	8.0	4.7	8.4	4.1	8.4	3.5
10. 9.0	6.2	9.0	5.7	9.0	5.1	9.1	4.7	9.5	4.1	9.5	3.5
11. 10.1	6.2	10.1	5.7	9.7	5.1	9.7	4.7	10.0	4.1	10.0	3.5

Table 4.48 Percent sludge removal by solvents at 20°C

S to O Ratio	%SR 1-butanol	S to O Ratio	%SR 2-propanol	S to O Ratio	%SR for MIBK	S to O Ratio	%SR for MEK
1. 1.5	2.1	1.4	1.8	2.1	1.7	1.9	1.2
2. 2.3	2.9	2.1	2.5	2.5	1.9	2.4	1.5
3. 2.5	3.6	2.5	3.0	3.2	3.1	3.0	2.4
4. 3.7	4.8	3.7	4.5	3.7	4.3	3.5	3.5
5. 4.6	5.7	4.6	5.4	4.6	4.8	4.5	4.5
6. 5.3	6.4	5.2	5.8	5.2	5.2	5.1	5.0
7. 5.7	6.8	5.5	6.3	6.2	6.0	6.0	5.7
8. 6.6	6.9	6.1	6.7	7.2	6.3	7.1	6.1
9. 7.3	7.4	6.8	6.8	8.3	6.5	8.1	6.2
10. 7.7	7.4	7.9	6.8	9.2	6.5	9.0	6.2
11. 9.5	7.4	9.1	6.8	10.2	6.5	10.1	6.2

Table 4.49 Percent sludge removal by solvents at 30°C

S to O Ratio	%SR 1-butanol	S to O Ratio	%SR 2-propanol	S to O Ratio	%SR for MIBK	S to O Ratio	%SR for MEK
1. 1.4	1.9	1.3	1.5	2.3	1.9	2.1	1.1
2. 2.1	2.3	2.1	1.9	2.7	2.7	2.5	2.1
3. 2.5	3.5	2.5	3.1	3.8	3.5	3.5	3.1
4. 3.7	4.6	3.6	4.3	4.4	4.3	4.2	3.7
5. 4.6	5.2	4.5	4.9	5.6	5.1	5.5	4.5
6. 5.2	5.6	5.1	5.1	6.1	5.5	6.0	5.2
7. 5.5	6.2	5.4	5.5	7.3	5.6	7.1	5.3
8. 6.1	6.7	6.0	6.3	7.8	5.9	7.5	5.5
9. 6.8	6.9	6.8	6.5	8.3	5.9	8.2	5.5
10. 7.9	6.9	7.8	6.5	9.2	5.9	9.0	5.5
11. 9.1	6.9	9.0	6.5	10.3	5.9	10.1	5.5

Table 4.50 Percent sludge removal by solvents at 40°C

S to O Ratio	%SR 1-butanol	S to O Ratio	%SR 2-propanol	S to O Ratio	%SR for MIBK	S to O Ratio	%SR for MEK
1. 1.7	1.9	1.6	1.5	2.4	1.5	2.3	1.2
2. 2.6	3.2	2.6	2.9	3.1	2.5	3.0	2.0
3. 3.7	3.9	3.7	3.7	3.8	3.3	3.5	2.7
4. 4.5	4.7	4.4	4.3	4.2	3.7	4.0	3.2
5. 5.1	5.5	5.0	4.9	4.9	4.1	4.7	3.7
6. 5.7	5.9	5.6	5.5	5.8	4.5	5.5	4.1
7. 6.4	6.1	6.3	5.7	6.7	5.1	6.5	4.8
8. 6.7	6.3	6.7	5.9	7.4	5.3	7.3	5.1
9. 7.3	6.3	7.2	5.9	8.5	5.3	8.3	5.1
10. 8.3	6.3	8.1	5.9	9.1	5.3	9.0	5.1
11. 9.1	6.3	9.1	5.9	9.9	5.3	9.7	5.1

Table 4.51 Percent sludge removal by solvents at 48°C

S to O Ratio	%SR 1-butanol	S to O Ratio	%SR 2-propanol	S to O Ratio	%SR for MIBK	S to O Ratio	%SR for MEK
1. 1.6	1.7	1.5	1.4	2.4	1.5	2.2	1.1
2. 2.4	2.7	2.3	2.4	3.2	2.0	3.0	1.7
3. 3.4	3.4	3.4	3.1	3.7	2.5	3.5	2.1
4. 4.1	4.1	4.0	3.7	4.3	2.8	4.1	2.5
5. 4.5	4.4	4.5	4.1	4.8	3.3	4.5	2.8
6. 5.0	4.8	5.0	4.4	5.6	3.8	5.5	3.5
7. 5.5	5.5	5.4	5.0	6.3	4.7	6.1	4.3
8. 6.3	5.8	6.1	5.5	7.3	4.9	7.2	4.7
9. 7.2	5.8	7.2	5.5	8.2	4.9	8.0	4.7
10. 8.1	5.8	7.9	5.5	9.3	4.9	9.1	4.7
11. 9.2	5.8	9.0	5.5	9.9	4.9	9.7	4.7

Table 4.52 Percent sludge removal by solvents at 50°C

S to O Ratio	%SR 1-butanol	S to O Ratio	%SR 2-propanol	S to O Ratio	%SR for MIBK	S to O Ratio	%SR for MEK
1. 1.5	1.5	1.4	1.3	2.4	1.2	2.3	1.0
2. 2.4	2.5	2.4	2.2	2.8	1.4	2.5	1.1
3. 3.4	2.9	3.3	2.7	3.2	1.6	3.0	1.2
4. 3.7	3.1	3.7	2.9	3.9	2.4	3.7	1.9
5. 4.2	3.6	4.1	3.3	4.5	3.1	4.5	2.7
6. 5.0	4.1	4.9	3.8	5.4	3.3	5.2	3.0
7. 5.8	5.1	5.6	4.7	6.8	4.3	6.6	3.9
8. 6.9	5.3	6.7	5.1	7.8	4.3	7.5	4.1
9. 7.2	5.3	7.0	5.1	8.6	4.3	8.4	4.1
10. 8.5	5.3	8.5	5.1	9.6	4.3	9.5	4.1
11. 9.0	5.3	8.9	5.1	10.2	4.3	10.0	4.1

Table 4.53 Percent sludge removal by solvents at 52°C

S to O Ratio	%SR 1-butanol	S to O Ratio	%SR 2-propanol	S to O Ratio	%SR for MIBK	S to O Ratio	%SR for MEK
1. 1.6	1.5	1.5	1.3	2.4	1.2	2.3	1.0
2. 2.1	1.9	2	1.5	2.8	1.5	2.5	1.1
3. 2.4	2.1	2.2	1.7	3.2	1.7	3	1.3
4. 3.5	2.8	3.5	2.6	3.9	2.3	3.7	2.0
5. 4.6	3.4	4.5	3.2	4.5	2.8	4.5	2.6
6. 5.4	3.8	5.4	3.5	5.4	3.2	5.2	2.9
7. 6.8	4.8	6.8	4.5	6.8	4.1	6.6	3.5
8. 7.1	4.8	7.0	4.5	7.8	4.1	7.5	3.5
9. 7.5	4.8	7.3	4.5	8.6	4.1	8.4	3.5
10. 8.5	4.8	8.2	4.5	9.6	4.1	9.5	3.5
11. 9.1	4.8	9.0	4.5	10.2	4.1	10	3.5

Table 4.54 Properties estimation of E_1 sample

Sample	a	b	t (sec)	viscosity(cst)	yield
E_1 with 50 % 1-butanol and 10 % Clay	0.00260	1.79	56	39.0	58.0
	0.00260	1.79	62	46.0	52.0
	0.00260	1.79	73	56.0	44.0
E_1 with 60 % 1-butanol and 8 % Clay	0.00260	1.79	57	40.0	58.5
	0.00260	1.79	63	47.0	53.0
	0.00260	1.79	74	56.5	45.8
$E_1$with 60 % 1-butanol and 10 % Clay	0.00260	1.79	57	40.0	59.0
	0.00260	1.79	64	47.5	51.5
	0.00260	1.79	74	57.0	45.0

Table 4.55 Properties estimation of E_2 sample

Sample	a	b	t (sec)	viscosity(cst)	yield
E_2 with 50 % 1-butanol and 10 % Clay	0.00260	1.79	59	45.0	61.0
	0.00260	1.79	74	57.0	54.0
	0.00260	1.79	83	69.0	47.0
E_2 with 60 % 1-butanol and 8 % Clay	0.00260	1.79	59	45.5	62.0
	0.00260	1.79	74	57.5	52.0
	0.00260	1.79	83	69.5	47.5
E_2 with 60 % 1-butanol and 10 % Clay	0.00260	1.79	59	45.5	61.0
	0.00260	1.79	74	57.5	54.5
	0.00260	1.79	84	70.0	47.0

Table 4.56 Properties estimation of E_3 sample

Sample	a	b	t (sec)	viscosity(cst)	yield
E_3 with 50 % 1-butanol and 10 % Clay	0.00260	1.79	63	47.5	64.0
	0.00260	1.79	74	57.5	59.5
	0.00260	1.79	79	63.5	52.0
E_3 with 60 % 1-butanol and 8 % Clay	0.00260	1.79	64	48.0	63.0
	0.00260	1.79	75	57.5	58.0
	0.00260	1.79	77	63.5	51.5
E_3 with 60 % 1-butanol and 10 % Clay	0.00260	1.79	64	48.5	66.0
	0.00260	1.79	75	58.0	60.5
	0.00260	1.79	78	64.0	52.0

Table 4.57 Properties estimation of E_4 sample

Sample	a	b	t (sec)	viscosity(cst)	yield
E_4 with 50 % 1-butanol and 10 % Clay	0.00260	1.79	58	41.5	60.0
	0.00260	1.79	72	53.5	56.0
	0.00260	1.79	81	65.0	53.0
E_4 with 60 % 1-butanol and 8 % Clay	0.00260	1.79	58	41.5	63.5
	0.00260	1.79	72	54.0	58.0
	0.00260	1.79	80	65.0	56.5
E_4 with 60 % 1-butanol and 10 % Clay	0.00260	1.79	58	41.5	62.5
	0.00260	1.79	72	54.0	56.0
	0.00260	1.79	81	65.5	53.5

Table 4.58 Properties estimation of E_5 sample

Sample	a	b	t (sec)	viscosity(cst)	yield
E_5 with 50 % 1-butanol and 10 % Clay	0.00260	1.79	63	49.0	60.5
	0.00260	1.79	73	56.0	54.0
	0.00260	1.79	82	68.5	49.0
E_5 with 60 % 1-butanol and 8 % Clay	0.00260	1.79	64	49.0	61.5
	0.00260	1.79	74	56.5	54.0
	0.00260	1.79	83	69.0	51.0
E_5 with 60 % 1-butanol and 10 % Clay	0.00260	1.79	66	49.5	61.0
	0.00260	1.79	74	57.0	52.5
	0.00260	1.79	83	69.5	49.0

Table 4.59 Properties estimation of E_6 sample

Sample	a	b	t (sec)	viscosity(cst)	yield
E_6 with 50 % 1-butanol and 10 % Clay	0.00260	1.79	66	48.5	59.0
	0.00260	1.79	71	53.5	55.0
	0.00260	1.79	76	60.0	52.0
E_6 with 60 % 1-butanol and 8 % Clay	0.00260	1.79	65	49.5	57.5
	0.00260	1.79	72	54.0	54.0
	0.00260	1.79	76	60.5	50.0
E_6 with 60 % 1-butanol and 10 % Clay	0.00260	1.79	66	50.5	60.5
	0.00260	1.79	72	54.0	55.5
	0.00260	1.79	66	61.0	53.0

Table 4.60 Properties estimation of E_7 sample

Sample	a	b	t (sec)	viscosity(cst)	yield
E_7 with 50 % 1-butanol and 10 % Clay	0.00260	1.79	71	53.5	66.0
	0.00260	1.79	74	57.0	61.0
	0.00260	1.79	81	68.0	54.0
E_7 with 60 % 1-butanol and 8 % Clay	0.00260	1.79	65	53.5	67.0
	0.00260	1.79	75	57.5	63.0
	0.00260	1.79	82	68.5	55.0
E_7 with 60 % 1-butanol and 10 % Clay	0.00260	1.79	71	54.0	67.0
	0.00260	1.79	75	58.0	62.0
	0.00260	1.79	83	69.0	54.0

Table 4.61 Properties estimation of E_8 sample

Sample	a	b	t (sec)	viscosity(cst)	yield
E_8 with 50 % 1-butanol and 10 % Clay	0.00260	1.79	61	45.5	62.5
	0.00260	1.79	76	60.0	59.5
	0.00260	1.79	84	69.5	57.0
E_8 with 60 % 1-butanol and 8 % Clay	0.00260	1.79	62	46.0	66.0
	0.00260	1.79	77	60.5	61.5
	0.00260	1.79	84	69.5	59.0
E_8 with 60 % 1-butanol and 10 % Clay	0.00260	1.79	62	46.0	65.0
	0.00260	1.79	77	61.0	61.0
	0.00260	1.79	85	70.0	58.0

Table 4.62 Properties estimation of E_9 sample

Sample	a	b	t (sec)	viscosity(cst)	yield
E_9 with 50 % 1-butanol and 10 % Clay	0.00260	1.79	77	58.5	67.0
	0.00260	1.79	87	74.0	66.0
	0.00260	1.79	90	87.0	64.0
E_9 with 60 % 1-butanol and 8 % Clay	0.00260	1.79	75	59.0	71.0
	0.00260	1.79	88	74.5	69.0
	0.00260	1.79	91	87.5	66.0
E_9 with 60 % 1-butanol and 10 % Clay	0.00260	1.79	75	59.0	72.0
	0.00260	1.79	88	75.0	70.0
	0.00260	1.79	92	88.0	67.0

Table 4.63 Properties estimation of E_{10} sample

Sample	a	b	t (sec)	viscosity(cst)	yield
E_{10} with 50 % 1-butanol and 10 % Clay	0.00260	1.79	77	61.5	73.0
	0.00260	1.79	85	73.0	72.0
	0.00260	1.79	89	83.0	70.0
E_{10} with 60 % 1-butanol and 8 % Clay	0.00260	1.79	77	62.0	74.0
	0.00260	1.79	88	75.0	72.5
	0.00260	1.79	89	84.0	70.5
E_{10} with 60 % 1-butanol and 10 % Clay	0.00260	1.79	77	62.5	75.0
	0.00260	1.79	82	76.0	73.5
	0.00260	1.79	83	84.5	71.5

Table 4.64 Properties estimation of G_1 sample

Sample	a	b	t (sec)	viscosity(cst)	yield
G_1 with 30 % 1- butanol	0.00247	0.5	113	154.4	86.0
	0.00247	0.5	114	155.0	85.5
	0.00247	0.5	115	155.4	85.0
G_1 with 40 % 1- butanol	0.00247	0.5	115	155.8	85.0
	0.00247	0.5	117	156.2	84.0
	0.00247	0.5	117	156.5	83.5
G_1 with 50 % 1- butanol	0.00247	0.5	118	157.0	84.5
	0.00247	0.5	118	157.5	84.0
	0.00247	0.5	119	158.0	83.0

Table 4.65 Properties estimation of G_2 sample

Sample	a	b	t (sec)	viscosity(cst)	yield
G_2 with 30 % 1- butanol	0.00247	0.5	131	200.5	81.5
	0.00247	0.5	132	201.0	82.5
	0.00247	0.5	132	201.5	81.0
G_2 with 40 % 1- butanol	0.00247	0.5	133	202.4	83.0
	0.00247	0.5	134	203.0	82.5
	0.00247	0.5	134	203.5	81.5
G_2 with 50 % 1- butanol	0.00247	0.5	135	204.0	81.5
	0.00247	0.5	136	204.5	83.0
	0.00247	0.5	137	205.0	81.0

Table 4.66 Properties estimation of G_3 sample

Sample	a	b	t (sec)	viscosity(cst)	yield
G_3 with 30 % 1- butanol	0.00247	0.5	143	230.2	82.0
	0.00247	0.5	143	230.5	81.5
	0.00247	0.5	144	231.2	81.0
G_3 with 40 % 1- butanol	0.00247	0.5	144	231.8	81.5
	0.00247	0.5	145	232.4	83.5
	0.00247	0.5	145	232.6	83.0
G_3 with 50 % 1- butanol	0.00247	0.5	146	233.6	83.0
	0.00247	0.5	147	234.0	82.5
	0.00247	0.5	148	234.5	82.0

Table 4.67 Properties estimation of G_4 sample

Sample	a	b	t (sec)	viscosity(cst)	yield
G_4 with 30 % 1- butanol	0.00247	0.5	153	273.8	81.5
	0.00247	0.5	154	274.0	83.0
	0.00247	0.5	154	274.5	83.5
G_4 with 40 % 1- butanol	0.00247	0.5	155	275.0	81.0
	0.00247	0.5	155	275.5	81.5
	0.00247	0.5	156	276.0	82.0
G_4 with 50 % 1- butanol	0.00247	0.5	159	276.5	81.0
	0.00247	0.5	160	277.2	83.0
	0.00247	0.5	162	277.6	82.0

Table 4.68 Properties estimation of G_5 sample

Sample	a	b	t (sec)	viscosity(cst)	yield
G_5 with 30 % 1- butanol	0.00247	0.5	176	330.4	82.5
	0.00247	0.5	177	330.8	82.0
	0.00247	0.5	179	331.2	82.0
G_5 with 40 % 1- butanol	0.00247	0.5	181	332.6	81.5
	0.00247	0.5	182	332.8	80.0
	0.00247	0.5	183	332.2	79.0
G_5 with 50 % 1- butanol	0.00247	0.5	183	333.4	79.5
	0.00247	0.5	185	333.8	81.0
	0.00247	0.5	187	334.0	81.5

Table 4.69 Properties estimation of C_1 sample

Sample	a	b	t (sec)	viscosity(cst)	yield
C_1 with 30 % 1- butanol	0.00260	1.79	47	30.0	81.4
	0.00260	1.79	49	30.5	80.6
	0.00260	1.79	50	31.0	79.0
C_1 with 35 % 1- butanol	0.00260	1.79	50	31.5	81.0
	0.00260	1.79	51	32.5	80.5
	0.00260	1.79	51	33.0	82.5
C_1 with 40 % 1- butanol	0.00260	1.79	52	33.0	78.6
	0.00260	1.79	52	33.5	79.0
	0.00260	1.79	53	34.0	77.5

Table 4.70 Properties estimation of C_2 sample

Sample	a	b	t (sec)	viscosity(cst)	yield
C_2 with 30 % 1- butanol	0.00260	1.79	58	41.0	82.0
	0.00260	1.79	59	41.5	82.5
	0.00260	1.79	59	42.0	81.0
C_2 with 35 % 1- butanol	0.00260	1.79	60	42.5	82.0
	0.00260	1.79	60	43.0	83.5
	0.00260	1.79	61	43.5	82.0
C_2 with 40 % 1- butanol	0.00260	1.79	61	43.5	83.5
	0.00260	1.79	62	44.0	83.5
	0.00260	1.79	63	44.5	84.0

Table 4.71 Properties estimation of C_3 sample

Sample	a	b	t (sec)	viscosity(cst)	yield
C_3 with 30 % 1- butanol	0.00260	1.79	77	61.5	81.5
	0.00260	1.79	77	62.0	82.0
	0.00260	1.79	78	62.5	80.5
C_3 with 35 % 1- butanol	0.00260	1.79	78	62.5	80.0
	0.00260	1.79	79	63.0	82.5
	0.00260	1.79	79	63.5	80.0
C_3 with 40 % 1- butanol	0.00260	1.79	80	64.0	78.0
	0.00260	1.79	81	64.5	77.5
	0.00260	1.79	82	65.0	81.0

Table 4.72 Properties estimation of H_1 sample

Sample	a	b	t (sec)	viscosity(cst)	yield
H_1 with 25% 1-butanol	0.00260	1.79	62	45.0	81.0
	0.00260	1.79	62	45.5	82.5
	0.00260	1.79	63	46.0	81.5
H_1 with 30% 1- butanol	0.00260	1.79	63	46.0	81.6
	0.00260	1.79	64	46.5	82.0
	0.00260	1.79	64	46.5	78.5
H_1 with 35% 1-butanol	0.00260	1.79	65	47.0	79.5
	0.00260	1.79	65	47.5	77.0
	0.00260	1.79	66	48.0	81.5

Table 4.73 Properties estimation of H_2 sample

Sample	a	b	t (sec)	viscosity(cst)	yield
H_2 with 25% 1-butanol	0.00260	1.79	85	71.0	76.4
	0.00260	1.79	85	71.0	76.0
	0.00260	1.79	86	71.5	81.6
H_2 with 30% 1- butanol	0.00260	1.79	86	72.07	81.5
	0.00260	1.79	86	72.0	80.3
	0.00260	1.79	87	72.5	81.0
H_2 with 35% 1-butanol	0.00260	1.79	87	73.0	78.5
	0.00260	1.79	88	73.5	78.2
	0.00260	1.79	89	74.0	78.8

Table 4.74 Properties estimation of H_3 sample

Sample	a	b	t (sec)	viscosity(cst)	yield
H_3 with 25% 1-butanol	0.00260	1.79	95	122.0	78.2
	0.00260	1.79	95	122.5	78.0
	0.00260	1.79	96	123.0	81.5
H_3 with 30% 1- butanol	0.00260	1.79	96	123.5	81.4
	0.00260	1.79	96	123.5	77.0
	0.00260	1.79	97	124.0	78.0
H_3 with 35% 1-butanol	0.00260	1.79	97	124.5	78.8
	0.00260	1.79	98	125.0	81.5
	0.00260	1.79	98	125.5	81.1

Table 4.75 Properties estimation of H_4 sample

Sample	a	b	t (sec)	viscosity(cst)	yield
H_4 with 25% 1-butanol	0.00247	0.5	139	223.0	81.2
	0.00247	0.5	139	223.6	78.0
	0.00247	0.5	140	223.9	78.0
H_4 with 30% 1- butanol	0.00247	0.5	140	224.3	81.6
	0.00247	0.5	141	224.7	80.2
	0.00247	0.5	141	225.0	80.0
H_4 with 35% 1-butanol	0.00247	0.5	141	225.4	81.4
	0.00247	0.5	142	225.8	82.0
	0.00247	0.5	142	226.6	81.2

Table 4.76 Properties estimation of H_5 sample

Sample	a	b	t (sec)	viscosity(cst)	yield
H_5 with 25% 1-butanol	0.00247	0.5	186	333.0	81.2
	0.00247	0.5	186	333.4	80.0
	0.00247	0.5	187	333.7	79.5
H_5 with 30% 1- butanol	0.00247	0.5	187	334.2	78.5
	0.00247	0.5	188	334.5	79.2
	0.00247	0.5	189	335.0	77.0
H_5 with 35% 1-butanol	0.00247	0.5	189	335.5	78.0
	0.00247	0.5	190	335.8	78.8
	0.00247	0.5	191	336.0	79.0

LIST OF PAPERS PUBLISHED

1. Vineet Katiyar and Sattar Husain, Regeneration of Used Lubricating Oil by using Solvent Extraction, National Conference in Advances in Petroleum Refining and Petrochemical Technology, Aligarh Muslim University, Aligarh, March 2009.

2. Vineet Katiyar and Sattar Husain, An Environmentally Friendly Process for the Regeneration of Used Lubricating Oils, International Conference on Emerging Technologies in Environment Science and Engineering, ICETESE, Aligarh Muslim University, Aligarh, October 2009.

3. Vineet Katiyar and Sattar Husain, Effect of Extraction on Recycling of Used Lubricating Oil, International Conference on Emerging Technologies in Environment Science and Engineering, ICETESE, Aligarh Muslim University, Aligarh, October 2009.

4. Vineet Katiyar and Sattar Husain, Treatment on Used Lubricating Oil, International Conference on Emerging Technologies in Environment Science and Engineering, ICETESE, Aligarh Muslim University, Aligarh, October 2009.

5. Vineet Katiyar and Sattar Husain, Reclamation of Used Lubricating Oils, Current World Environment, Vol. 5(1), pp.79-84, 2010.

6. Vineet Katiyar and Sattar Husain, Recycling of Used Lubricating Oil using 1-butanol, International Journal of Chemical Science, Vol.8(3), pp. 1999-2012, 2010.

7. Vineet Katiyar and Sattar Husain, Used Lubricating Oils Recycling Using Solvent Extraction, Current World Environment, Vol. 5(1), pp.23-29, 2010.

8. Vineet Katiyar and Sattar Husain, Environmental Impacts of Used Oil, Material Science Research India, Vol.7(1), pp.245-248, 2010.

9. Vineet Katiyar and Sattar Husain, Effects of treatment on Quality of Used Lubricating Oil, Environmental Pollution Control Journal, Vol.12, pp.60-65, No.6, 2009.

10. Vineet Katiyar and Sattar Husain, Disposal of Used Lubricating Oils, International Conference on Emerging Technologies for Sustainable Environment, Aligarh Muslim University, Aligarh, pp.420-423, October 2010.

11. Vineet Katiyar and Sattar Husain, Health and Safety Aspects of Used Lubricating Oils using 1-butanol, International Journal of Chemical Science, Vol.8(4), pp. 2775-2783, 2010.

12. Vineet Katiyar and Sattar Husain, Hazardous waste – Used oil, International Conference on Emerging Technologies for Sustainable Environment, Aligarh Muslim University, Aligarh, pp.424-426, October 2010.